U.S. DEPARTMENT OF COMMERCE
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PB-274 874

Wastewater Characterization and Process Reliability for Potable Wastewater Reclamation

Dallas Water Utilities Dept, Tex

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

Nov 77

EPA-600/2-77-218
November 1977

PB 274 874

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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NATIONAL TECHNICAL
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U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-210
2.
3. RECIPIENT'S ACCESSION NO. PB274874
4. TITLE AND SUBTITLE WASTEWATER CHARACTERIZATION AND PROCESS RELIABILITY FOR POTABLE WASTEWATER RECLAMATION
5. REPORT DATE November 1977 (Issuing Date)
6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Albert C. Petrasek, Jr.
8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS

Dallas Water Utilities
Dallas, Texas 75201

10. PROGRAM ELEMENT NO. 1 BC 611
11. CONTRACT/GRANT NO. R - 803292
12. SPONSORING AGENCY NAME AND ADDRESS

Municipal Environmental Research Laboratory--Cin.,OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED Final/1974-1975
14. SPONSORING AGENCY CODE EPA/600/14
15. SUPPLEMENTARY NOTES

Project Officer: John English Phone: 513/684-7613

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste Treatment *Water Reclamation, Nutrients Nutrients Reliability	*Wastewater Reuse Heavy Metal *Tertiary Treatment Dallas, Texas	13 B

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 126
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC A07- A01

EPA Form 2220-1 (9-73)

☆U.S. GOVERNMENT PRINTING OFFICE: 1977— 757-140/6593

EPA-600/2-77-210
November 1977

WASTEWATER CHARACTERIZATION AND PROCESS RELIABILITY FOR POTABLE WASTEWATER RECLAMATION

by

Albert C. Petrasek, Jr.
Texas A&M University

for

Dallas Water Utilities
Dallas, Texas 75201

Project No. R-803292-01

Project Officer

John English
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study described here was undertaken to evaluate the performance and reliability of an advanced wastewater treatment system designed to produce an effluent suitable for reuse for potable purposes. Sound management of water resources must include consideration of all potential uses of properly treated municipal wastewater as alternatives for meeting future water demands.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This research effort was initiated to quantify water quality criteria of importance in evaluating the performance of a wastewater treatment facility producing a product water potentially available for potable reuse. Additionally, the reliability of individual unit processes was evaluated and the effects of process instability on product water-quality were investigated.

The sequence of unit processes utilized in the study to treat municipal wastewater consisted of screening, degritting, primary clarification, biological treatment with completely-mixed activated sludge, high-pH lime coagulation, single-stage recarbonation with liquid carbon dioxide, gravity filtration, and two-stage activated carbon adsorption. Flows through the pilot plant ranged from 9.6 liters per second (152 gpm) for the activated sludge influent to 1.1 liters per second (18 gpm) for the product water. Twenty-four-hour composite samples were collected daily for routine analyses; weekly composite samples were utilized for metals determinations.

The final product water complied with the quality criteria of the National Interim Primary Drinking Water Regulations in all respects. Significant process instabilities had little effect on product water quality due to the redundant nature of the treatment system employed.

This report was submitted in partial fulfillment of Grant No. R-803292-01 by the Water Utilities Department, City of Dallas, Texas under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 1, 1974 to January 31, 1975.

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ACKNOWLEDGMENTS

This report is the product of cooperative effort by so many people that individual mention becomes unfeasible. To the entire group of Dallas Water Utilities personnel and the Texas A&M Research Foundation members we want to convey our gratitude for their support and cooperation.

In particular we want to offer our thanks to Mr. Henry J. Graeser, Director, Dallas Water Utilities, who originated the plan and inspired the effort; Dr. I. M. Rice, Assistant Director for Engineering and Planning during the program and since the successor to Mr. Graeser as Director, for grant preparation and financial planning in addition to general grant administration; and to Dr. Harold W. Wolf, Texas A&M Professor of Civil Engineering and Project Director for his guidance, advice, and constant effort in executing the program

SECTION I

INTRODUCTION

As shown in Figure 1, the City of Dallas in north central Texas is situated in the upper Trinity River Watershed. This region must be classified as naturally water deficient; in fact, there is only one natural lake in the whole State of Texas. In the upper Trinity River Basin, average annual precipitation ranges from about 40 inches per year in the eastern portions to 20 inches per year in the westerly sections. In general, average annual precipitation and evaporation rates are about equal, and drought periods in excess of 60 days are not uncommon. These factors combine to make water a very valuable resource in North Central Texas.

The City of Dallas derives its drinking water supply from the extensive reservoir network shown in Figure 1, and estimates indicate that an adequate supply of fresh water exists to meet demands anticipated to the year 1995. The water supply is derived from six reservoirs on three watersheds, with estimated safe yields for the year 2020 indicated in Table 1.

During the middle 1950's North Central Texas experienced a protracted drought. The City of Dallas investigated two alternate sources of water to augment its dwindling supply. One was to pump water from the highly mineralized Red River into the existing reservoir system, and the other was to utilize the waters of the West Fork of the Trinity River which carry a considerable amount of pollution from the wastewater effluents of the City of Ft. Worth and of the mid-cities between Ft. Worth and Dallas. In 1955 the thought of "drinking someone else's sewage" did not meet with wide acceptance from either the general public or the City Council and the decision was made to import water from the Red River. Consequently, the City survived the drought by utilizing the Red River over a three-year period -- but not without effect (1). A most important point emerging from this period is that as early as 1955 a major American city had seriously evaluated the possibility of an indirect wastewater reuse as an alternate supply of drinking water.

With respect to total water resources management in the upper Trinity River Basin indirect but intentional wastewater reuse is of considerable importance to the City of Dallas. Both the Bachman and the Elm Fork Water Purification Plants of the City of Dallas withdraw water from the Elm Fork of the Trinity River. Estimated water supply for the year 2020 includes 328,573 cu m per day (86.8 MGD) from Garza-Little Elm Reservoir, 37,854 cu m per day (10.0 MGD) from Grapevine Reservoir, and 156,337 cu m per day (41.3 MGD) in return flows. The return flows are composed exclusively of wastewater effluents discharged approximately 33 kilometers (20 miles) upstream from the water plant intake structures. The return flows constitute 30

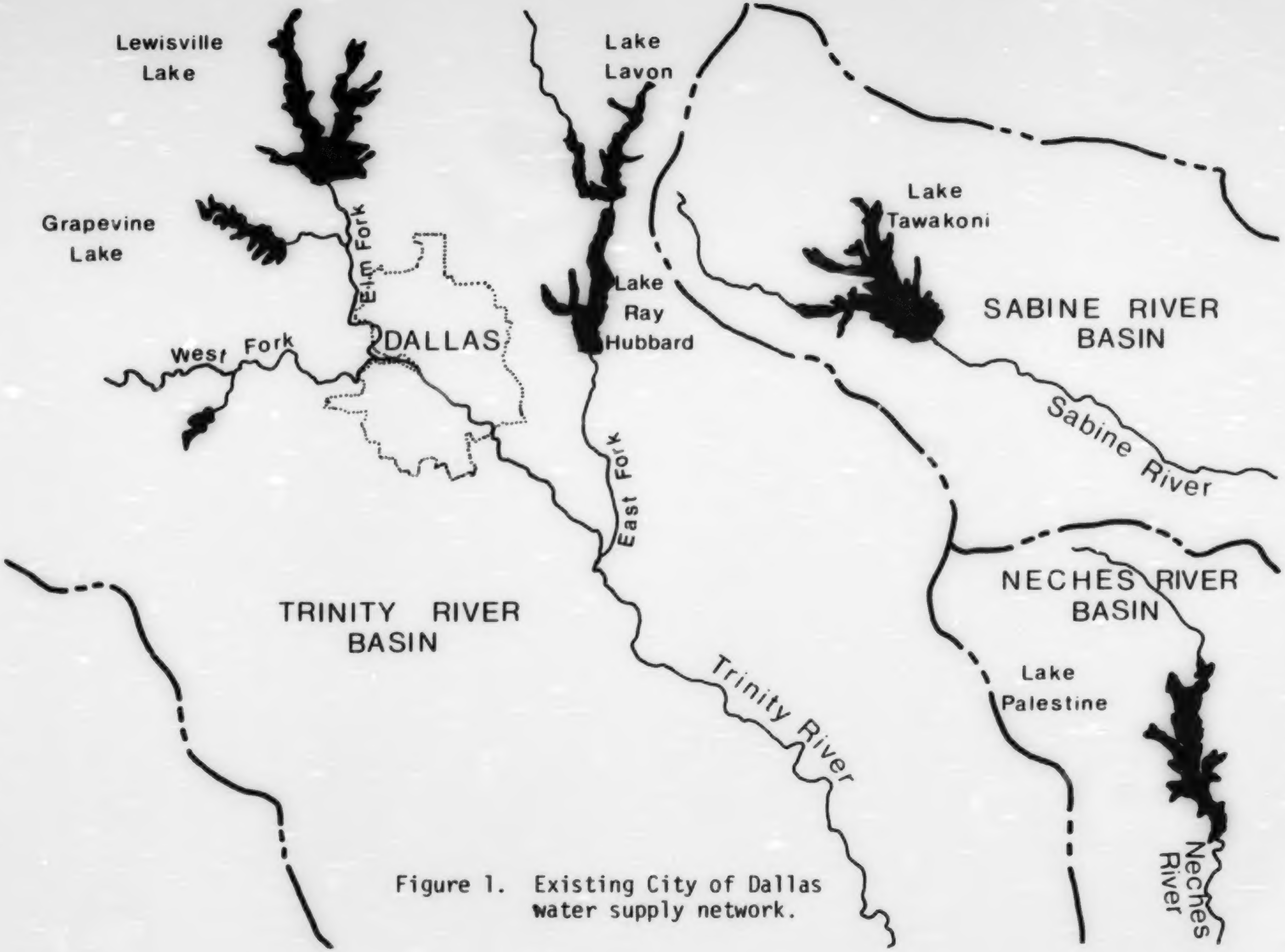
Lewisville Lake
Grapevine Lake
West Fork
Elm Fork
DALLAS
Lake Lavon
Lake Ray Hubbard
East Fork
Lake Tawakoni
SABINE RIVER BASIN
Sabine River
NECHES RIVER BASIN
Lake Palestine
Neches River
TRINITY RIVER BASIN
Trinity River

Figure 1. Existing City of Dallas water supply network.

TABLE 1

SUMMARY OF EXISTING WATER SUPPLY FOR THE YEAR 2020

Reservoir and Basin	Estimated Safe Yield MGD	M^3/day
Trinity River Basin		
Lewisville (Garza-Little Elm)	86.8	328,573
Grapevine	10.0	37,854
Ray Hubbard	55.4	209,711
Lavon	10.0	37,854
Return flows	41.3	156,337
Sabine River Basin		
Tawakoni	162.8	616,263
Neches River Basin		
Palestine	102.0	386,111
TOTAL AVAILABLE SUPPLY	468.3	1,772,703

percent of the 522,764 cu m per day (138.1 MGD) that will be used as a source of drinking water, and represent a valuable water resource. However, travel time from the point of discharge to the most distant intake structure is less than one day, allowing little time for significant natural purification to occur. Under these circumstances, the City of Dallas has considerable interest in water and wastewater treatment technology since it is imperative that the public health be safeguarded.

Bearing in mind the occasional shortages of rainfall and the consequences of a prolonged drought, and knowing also that new sources of supply are disappearing rapidly, the City of Dallas has felt for some years that the building of new reservoirs on streams to augment the potable water supply would become virtually impossible. The fact that eastern cities in particular have been able to produce potable, palatable waters from rivers that have been increasingly polluted has led to consideration that some day the actual recycle of waste waters, properly treated, may actually be a means of survival in the semiarid southwest and west.

Dallas has for several years pursued studies of wastewater and water treatment methods that might lead to the production of potable water completely acceptable for all uses. Because there are technological, legal, and esthetic considerations to be satisfied, Dallas has followed a cautious policy that more than is known now must be learned about constituents of any water proposed for reuse, the three large areas still relatively unsatisfied being viruses, heavy metals, and organics. Any or all of these may be found to some degree in recycled waters, and enough work must be done to satisfy all parties that no risk attaches to either health or comfort from the prolonged use of such waters. Dallas will want to know that the most stringent standards can be met before proposing recycle.

BACKGROUND OF THE DALLAS PROGRAM

As a result of the previously described circumstances, namely, the consideration of using the heavily polluted West Fork of the Trinity in 1955, the present indirect use of upstream effluents, however minor, and the economics dictating that maximal amounts of wastewaters be salvaged if practical, the Dallas Water Utilities have pursued an active, viable wastewater reuse program since June 1970. Available wastewater flow is shown in Figure 2.

The Demonstration Plant of the Dallas Water Reclamation Research Center, which is described in detail in a subsequent section of this report, was built and brought on-line in late July 1969. Equipment check-out and/or modification consumed at least nine months, and the facility was in service for almost a year before the staff considered it to be truly operational. Additionally, a laboratory and administration building was constructed to provide laboratory capabilities for the research program and office space for several different Water Utilities Department activities. The laboratory facilities were occupied in the Spring of 1971.

The funds for construction of the laboratory and administration building were provided by Federal Grant No. WPC Tex 588, to the amount of $571,093 of which the City provided 52 percent. The Demonstration Plant was

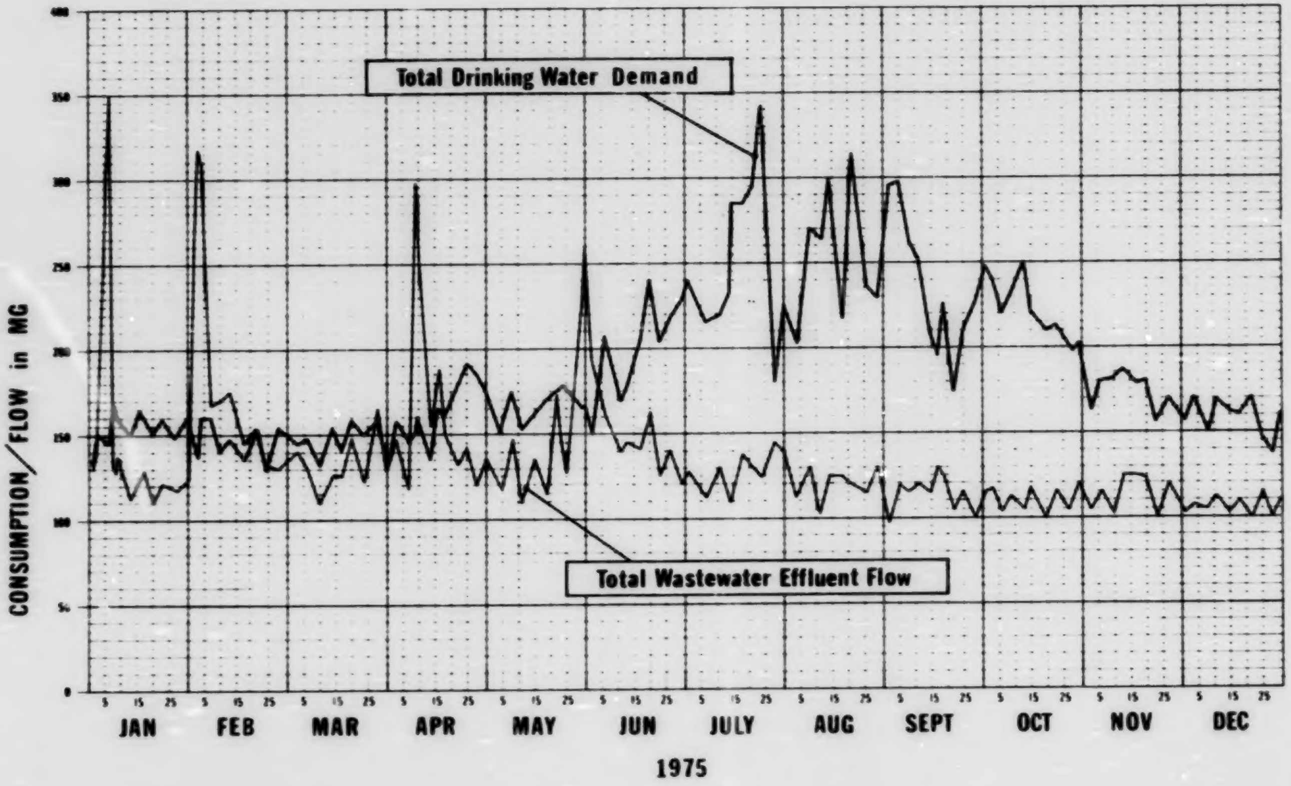

Figure 2. Potable water supplied and wastewater flows for 1975.

constructed under Grant No. 17080 EKG from the Environmental Protection Agency (EPA) for a total cost of $689,015 of which the City of Dallas provided 45 percent.

From start-up until January 1971 the Dallas Water Reclamation Research Center operated on additional funds provided in Grant No. 17080 EKG for the study of various water reclamation unit processes. The initial phase of the project was directed at evaluating different sequences of unit processes to expand and up-grade the City's Central Wastewater Treatment Plant.

At the conclusion of these studies additional unit processes were investigated by utilizing a number of different wastewaters as influents to the unit processes at the Demonstration Plant. For the most part the investigations were short term (2 to 4 weeks), and these data have been presented in the Final Report for the project (2).

From June 1972 through February 1974 the Research Center evaluated the removal of metals and viruses through three different advanced wastewater treatment sequences. Concentrations for over twenty different metals were evaluated in the influent and effluent of each unit process over the protracted study period. This project was funded through Grant No. S-801026 from EPA for a total cost of $200,287, of which the City shared 41 percent (3,4).

RESEARCH PRESENTED IN THIS REPORT

The present project, Grant No. S-803292-01, was started in June 1974 and concluded during November 1975. This project was conducted in two phases, both of which had distinctly different research objectives.

Characterization for Potable Reuse

In the first part of this research effort the selected treatment train was operated to produce the best possible quality of effluent. This product water was then examined in the light of present and proposed standards for its potential reuse as a potable water. The research objectives were:

1. Production of a high-quality product water.
2. Monitoring of the effluent for parameters to indicate whether potable quality according to available criteria had been achieved.
3. Evaluating the reliability of the sequence of unit processes utilized in the study as it relates to wastewater reuse.

Ultraviolet Disinfection of Municipal Effluents

Phase two of this project was a study of the feasibility of utilizing ultraviolet light as a disinfection process for municipal wastewater effluents . The objectives of the ultraviolet disinfection project were as follows:

1. Evaluate the feasibility of using ultraviolet light as a disinfection process for municipal wastewater effluents.
2. Determine what, if any, additional treatment is required to achieve fecal coliform counts less than 200 per 100 ml on a consistent basis.
3. Evaluate the effect of photo-reactivation on ultraviolet disinfection by performing light/dark studies.

This research effort was conducted for a total cost of $262,754, of which the EPA provided 27 percent of the funds and the City of Dallas the remainder.

Since the two portions of the study had such different objectives, this report discusses only the research effort conducted during the first phase of the project. The work performed on ultraviolet disinfection will be presented in a separate report.

SECTION II

CONCLUSIONS

The sequence of unit processes used in this research effort, i.e. screening, degritting, primary clarification, biological treatment with completely-mixed activated sludge, high-pH lime coagulation, single-stage recarbonation, gravity filtration, and activated carbon adsorption through two gravity-flow contactors operating in series, produced a consistently high-quality product water. When evaluated in terms of mean observed concentrations, the product water easily complied with the criteria for maximum contaminant levels (MCL) for potable water promulgated by the U.S. Environmental Protection Agency in the National Interim Primary Drinking Water Regulations (NIPDWR).

During this study the activated sludge system experienced one major process upset that resulted in very high COD and TSS concentrations in the effluent from the biological process. However, the 87 minute empty-bed contact time in the activated carbon adsorption system was sufficient to prevent any significant increase in the COD concentrations in the product water, and for this reason extended empty-bed contact time should be considered in the design for potable wastewater reuse.

Although turbidity breakthrough did occur on the mixed-media filter as a possible result of improper backwashing procedure, the downflow carbon contactors provided important supplementary filtering capacity such that the turbidity of the product water was not increased significantly. Difficulties with filter performance should be minimal under normal operating conditions, but the redundancy gained by using downflow carbon columns is a significant factor to be considered when designing a facility for potable reuse.

The metals removals observed during this study were quite variable, ranging from an increase for mercury to an 85.6 percent reduction for arsenic. Every metal for which there is a standard in the NIPDWR was substantially reduced in concentration by the activated sludge process, and for this reason one may conclude that biological processes are important in limiting the metals concentrations in the product water. Additionally, most of the metals with well-defined adverse health effects were reduced in concentration by at least 50 percent. Considering the concentrations and removals of the various metals observed during this research, the best technique for controlling metals concentrations in the product water is to limit metals discharges into the collection system, and then employ an effective treatment sequence.

Operation of the activated sludge system to achieve complete nitrification is important for a facility producing an effluent for potable reuse and employing the same treatment sequence used in this study. Lower soluble

COD concentrations will result from operation at the elevated sludge ages necessary to develop an adequate population of nitrifying microorganisms. If the activated sludge process is operated to nitrify, and long empty-bed contact times are provided in the carbon adsorption system, the production of a product water with a very low COD concentration (0-3 mg/l) is feasible.

Certain water quality parameters that were routinely monitored during this study have great utility as process control parameters for wastewater reclamation facilities that are producing a product water intended for potable reuse. Since operation of the activated sludge process in a nitrifying mode produces water with a lower COD, and since chlorination as a disinfection process is affected by the presence of ammonia, ammonia nitrogen and organic nitrogen are extremely valuable process control parameters. Monitoring and control of pH on the lime coagulation and recarbonation processes is essential if process performance and cost effectiveness are to be maximized. Alkalinity determinations can be used for process control on the chemical treatment systems, and since alkalinity is destroyed during nitrification it is a valuable process control tool for the biological process.

Control of product water turbidity is important for proper disinfection, and the turbidity of various process flows is an important indication of how well the individual unit processes are operating. With the singular exception of biochemical oxygen demand (BOD_5) -- because of the five-day period -- all of the gross organic parameters have the capability of being important process control parameters.

During this study no nitrogen removal process per se was incorporated in the treatment sequence. Nitrate nitrogen concentrations were consistently below the 10 mg/l standard promulgated in the NIPDWR, but higher nitrate nitrogen concentrations can and should be anticipated. Under these circumstances nitrogen removal will probably be necessary, although the process utilized may only be required to treat 25 to 50 percent of the total product flow.

The product water produced during this study easily complied with the criteria promulgated in the NIPDWR; however these water quality criteria were not developed for potable water derived from wastewater and the comparison must be viewed with this in mind.

SECTION III

RECOMMENDATIONS

The following recommendations are made as a result of the potable reuse research program conducted at the Dallas Water Reclamation Research Center, and the experience gained during operation of the Demonstration Plant.

1. Since the consistent production of a high-quality product water is essential for potable reuse, every effort should be made to optimize the reliability of the entire treatment sequence and each individual unit process.

    a. Demonstrated reliability of the mixing and oxygen transfer equipment used in the activated sludge system should be considered more important than mass transfer efficiency, since mechanical failure will adversely effect all subsequent unit processes and product water quality will be impaired.

    b. Chemical feed equipment should be sized and duplicated so that both reserve capacity and standby capacity assure continuing of operation.

    c. All chemical feed lines, and especially the lime feed lines, must be accessible for routine cleaning and scale removal.

    d. If high pH lime coagulation is employed, the effluent from the chemical clarifier should flow by gravity to the recarbonation basin to avoid scale formation in pumps.

    e. Two-stage recarbonation with intermediate clarification should be used to improve calcium removal and reduce the hardness of the product water.

    f. Down-flow carbon contactors should be used so that the facility will have a redundant filtering capability.

2. Significant removals of toxic metals were observed during this project. However, the employment of adequate processes to remove metals should also be accompanied by a source control program so that metal discharges into the municipal wastewater system can be carefully controlled and limited.

3. High pH (> 11.2) lime coagulation is a very effective disinfection process, and for this reason should be considered in the design of any potable reuse treatment sequence.

4. The activated sludge process should be operated to nitrify such that the COD loading to the activated carbon adsorption system will be reduced, and performance of the carbon improved.

5. Additional research should be performed to evaluate the capabilities of high-pH lime coagulation as a disinfection process. Particular emphasis should be placed on the destruction of parasitic organisms and enteric viruses.

SECTION IV

DESCRIPTION OF RESEARCH FACILITIES

CITY OF DALLAS COLLECTION SYSTEM

The sanitary sewer collection system serving the City of Dallas consists of 5074.005 kilometers (3,136.734 mi) of gravity mains. The lengths of mains of different diameters are summarized in Table 2. During the fiscal year covered in this report the City abandoned 2.536 kilometers (1.576 mi) of sanitary sewer main, and added 35.094 kilometers (21.811 mi) of mains to the collection system. The best available estimates indicate that the total length of laterals is between one and two times the length of the gravity mains, indicating a total collection system length between 10,000 and 15,000 kilometers (6215 and 9323 miles). The City has no combined sewers.

In addition to the normal domestic wastes discharged to the collection system, the City has significant contributions from industrial and commercial establishments. During fiscal year 1974 the industrial discharges represented 12.1 percent of the total flow received at the Central Plant, or 21.93×10^6 cu.m. (5.794×10^9 gal) per year. The 221 significant industries monitored by the Water Utilities Department discharged a total of 1.70×10^7 kg of BOD_5 (3.7396×10^7lbs) and 1.375×10^7 kg (3.0263×10^7 lbs) of total suspended solids TSS to the collection system. When expressed in terms of concentration, the BOD_5 and TSS of the industrial discharges are 773 mg/l and 626 mg/l, respectively. The BOD_5 discharge represents 37.7 percent of the total load entering the Central Plant, while the industrial TSS discharges represent 30.7 percent of the total TSS load.

The activities of commercial establishments, including restaurants, wholesale food preparation facilities, and service facilities (principally car washes), have substantial impact on wastewater characteristics. Generalized information relating to the industrial and commercial discharges are summarized in Table 3. The predominant effect of commercial activities is to increase the organic and solids loadings; however, certain of the service activities (car washing) can have appreciable impact on metals concentrations.

The concentrations of certain metals in the influents of the Dallas and White Rock plants are given in Table 4. The column headed "combined" is a calculated, flow-weighted concentration for all wastewaters arriving at the Central Plant which comprises both the Dallas and White Rock plants. Typical data for raw wastewater entering the White Rock STP are presented in Table 5, and upon inspection the wastewater appears to be representative of domestic wastewaters. Most of the industrial waste discharges enter the Dallas STP, and for this reason the wastewaters entering the White Rock plant are more suitable for wastewater reuse studies.

TABLE 2

SIZES AND LENGTHS OF GRAVITY MAINS IN THE SANITARY SEWER COLLECTION SYSTEM

PIPE DIAMETER		LENGTH	
(cm)	(in)	(km)	(mi)
10.16	4	2.513	1.562
15.24	6	1814.508	1127.724
20.32	8	1934.113	1202.059
25.40	10	450.758	280.148
30.48	12	244.624	152.035
35.56	14	0.759	0.472
38.10	15	176.397	109.658
40.64	16	0.290	0.180
45.72	18	123.037	76.468
53.34	21	59.057	36.704
60.69	24	47.435	29.481
68.58	27	21.334	13.259
76.20	30	40.954	25.453
83.82	33	8.367	5.200
91.44	36	22.632	14.066
99.06	39	7.435	4.621
106.68	42	12.790	7.949
114.30	45	7.416	4.609
121.92	48	16.939	10.528
129.54	51	0.454	0.282
137.16	54	10.095	6.274
152.40	60	26.182	16.272
160.02	63	0.732	0.455
167.64	66	3.560	2.236
182.88	72	8.333	5.179
198.12	78	1.936	1.203
205.74	81	0.714	0.444
213.36	84	1.263	0.785
228.60	90	2.248	1.397
Total length of mains	=	5,047.005	3,136.734

TABLE 3

SUMMARY OF INDUSTRIAL AND COMMERCIAL DISCHARGES TO THE COLLECTION SYSTEM

Type of Business	Number of Establishments	---------Flow---------		BOD$_5$	TSS	Grease
		(cu.m./mo.)	(gal./mo.)	(mg/l)	(mg/l)	(mg/l)
Industrial	221	1.824×10^6	4.82×10^8	773	626	---
Commerical						
Restaurants	1700	---------	---------	1158	1059	320
Wholesale Food Preparation	200	---------	---------	903	678	183
Service Facilities	300	---------	---------	268	1079	203
Total Commercial	2200	3.9547×10^5	1.05×10^8	----	----	---

TABLE 4

INFLUENT METALS CONCENTRATIONS FOR FISCAL YEAR 1975

Metal	-----------Concentration (mg/1)-----------		
	Dallas STP	White Rock STP	Combined
Arsenic	0.00474	0.02003	0.0164
Barium	0.660	0.700	0.691
Boron	0.507	0.387	0.416
Cadmium	0.035	0.016	0.0205
Chromium	0.345	0.114	0.169
Copper	0.234	0.142	0.164
Lead	0.443	0.193	0.252
Manganese	0.096	0.080	0.084
Mercury	0.00159	0.00125	0.001331
Nickel	0.210	0.088	0.117
Selenium	-------	-------	-------
Silver	0.0170	0.0155	0.0159
Zinc	0.580	0.227	0.311

TABLE 5

CHARACTERISTICS OF RAW WASTEWATER AT THE WHITE ROCK STP FOR THE PERIOD OF OCTOBER 1, 1974 THROUGH SEPTEMBER 30, 1975

Flow = 408,823 cu.m./day (108.0 MGD)

Grit = 0.0127 liters/cu.m. (1.69 cu.ft./MG

Total Solids = 844 mg/l

Settleable Solids = 8.4 mg/l

TSS = 209 mg/l

COD = 417 mg/l

BOD_5 = 191 mg/l

NH_3-N = 16.4 mg/l

Org. N. = 13.5 mg/l

NO_2 & NO_3-N = 0.3 mg/l

pH = 7.2

DEMONSTRATION PLANT

The Demonstration Plant of the Dallas Water Reclamation Research Center is colocated with the White Rock Sewage Treatment Plant (STP) at the City of Dallas' Central Wastewater Treatment Facility. The Central Plant complex is situated on the south bank of the Trinity River approximately five kilometers (3 miles) south of the City's central business district. The Central Plant actually consists of the three treatment facilities described below, two of which are trickling filter plants. The third facility is completely-mixed activated sludge followed by tertiary mixed-media filtration.

Dallas Sewage Treatment Plant

The Dallas STP is the oldest wastewater treatment facility operated by the City of Dallas. This single-stage, standard-rate, trickling filter facility consists of four bar screens and grit channels, twenty-four Imhoff tanks which are operated as primary clarifiers, two rectangular primary clarifiers, sixteen standard-rate trickling filters which are 53 meters (174 feet) in diameter, and three final clarifiers.

White Rock Sewage Treatment Plant

The White Rock STP is a two-stage, high-rate trickling filter facility without intermediate clarification. The plant consists of two bar screens and grit channels, six rectangular primary clarifiers, four first-stage, high-rate trickling filters, eight second-stage, high-rate trickling filters, and four rectangular final clarifiers. All trickling filters are 53 meters (174 feet) in diameter, and contain a maximum of 2.286 meters (7.5 feet) of media.

Tertiary Treatment Complex

Under normal flow conditions the effluents from both the Dallas and White Rock facilities will be discharged to the tertiary treatment complex prior to discharge into the Trinity River. The tertiary complex consists of twelve completely-mixed, activated sludge aeration basins and twelve final clarifiers, followed by fourteen mixed-media gravity filters. This facility is scheduled to come on-line during the fall of 1976, and pilot plant research indicates that considerable improvement in water quality in the Trinity River can be anticipated.

The physical relationship between the individual facilities present at the Central Plant complex can be seen in Plate 1.

Demonstration Plant

All influents to the Demonstration Plant are pumped from the White Rock STP and all effluents and sludges from the pilot plant are returned to the headworks of the White Rock plant. As indicated in Figure 3, there are a total of five possible influents which can be supplied at a maximum flow of 47.32 liter/sec (750 gpm), with the exception of the raw sewage pump that is rated at 18.93 liter/sec (300 gpm). The discharges from all pumps are

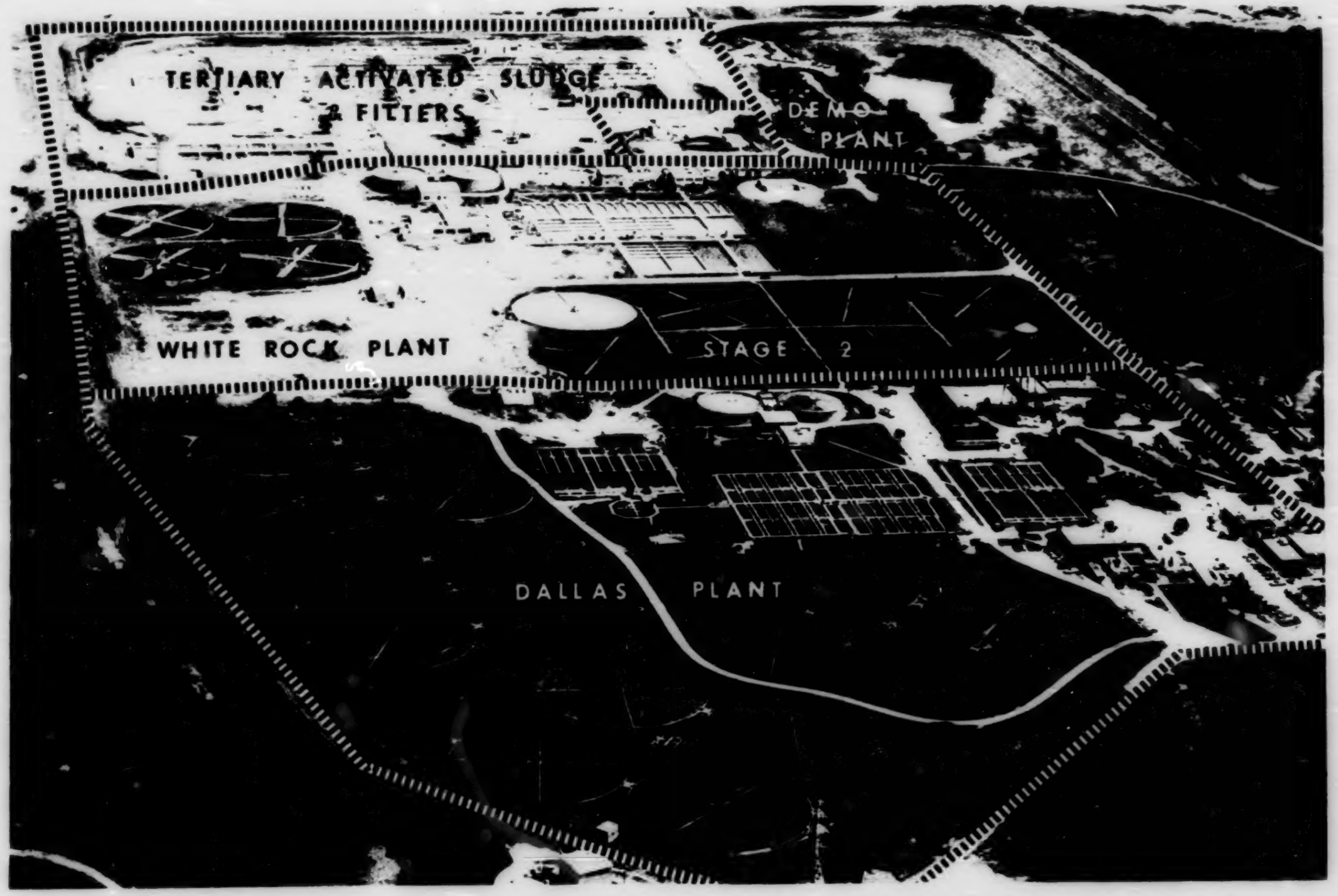
TERTIARY ACTIVATED SLUDGE
& FILTERS
DEMO PLANT
WHITE ROCK PLANT
STAGE 2
DALLAS PLANT

Plate 1. Overall view of the Central Wastewater Treatment Plant looking south.

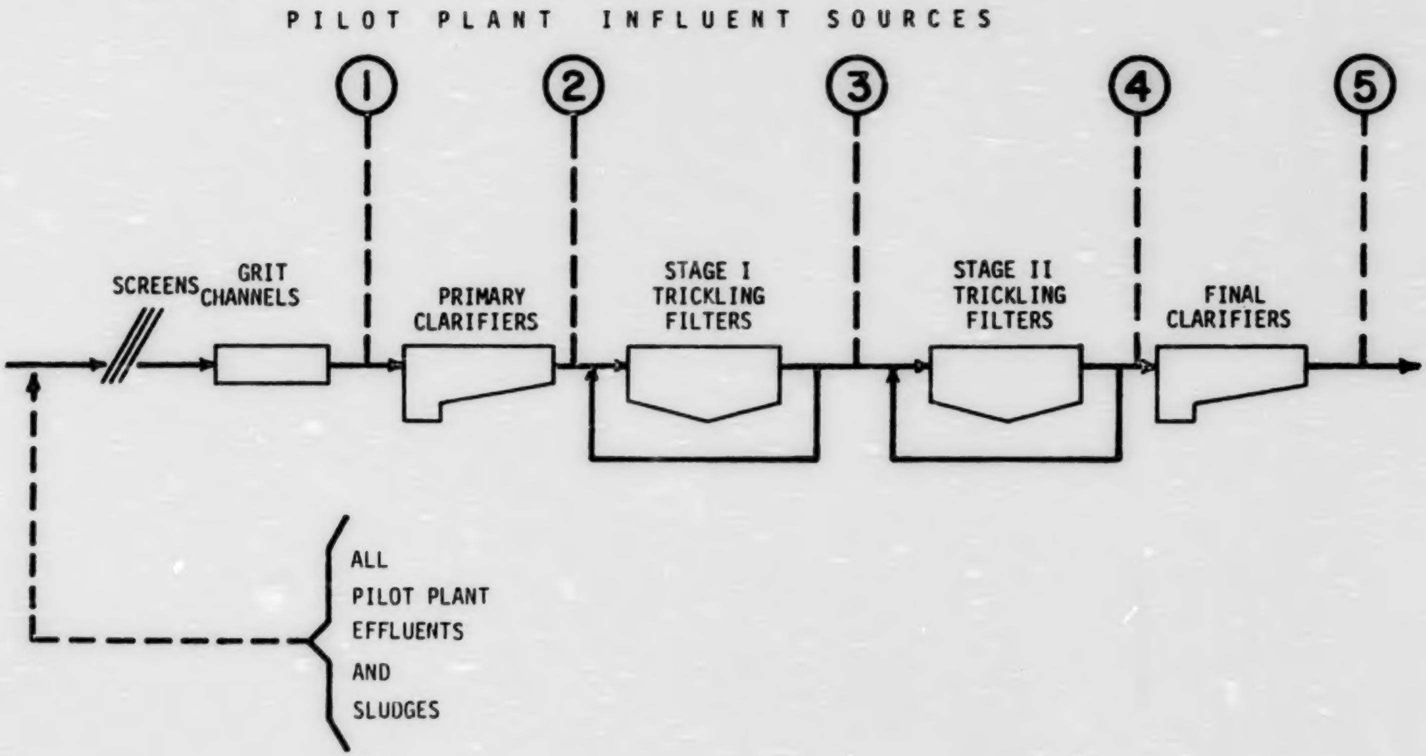
PILOT PLANT INFLUENT SOURCES
1
2
3
4
5
SCREENS
GRIT CHANNELS
PRIMARY CLARIFIERS
STAGE I TRICKLING FILTERS
STAGE II TRICKLING FILTERS
FINAL CLARIFIERS
ALL PILOT PLANT EFFLUENTS AND SLUDGES

Figure 3. Possible sources of influents for the Pilot Plant at the White Rock Sewage Treatment Plant.

routed to a valve station at the White Rock plant, from which the flow is directed to the pilot plant through one of three main influent lines. Each influent line services one of the major treatment modules (biological, chemical, or physical) at the Demonstration Plant.

As indicated in Figure 4, which is a piping diagram of the major components of the Demonstration Plant, the facility is relatively complex and very flexible. The following unit processes are present at the pilot plant. They are discussed in detail in the following sections of this report, and many are identified in Plate 2 (aerial photograph of the Demonstration Plant.)

1. No. 1 completely-mixed activated sludge system
2. No. 2 completely-mixed activated sludge system
3. Upflow clarifier
4. Gravity-flow, mixed-media filter
5. Gravity-flow, dual-media filter
6. Gravity-flow activated carbon contactors (2 each)
7. Chlorine contact basins (2 each)
8. Ozone generator and contacting system
9. Reverse osmosis demineralization unit
10. Ultraviolet light disinfection units (2 each)
11. Chemical storage and feeding equipment

No. 1 Activated Sludge System --

The No. 1 activated sludge system consists of the No. 1 aeration basin and the No. 1 final clarifier, and return sludge and effluent pumps. The return sludge pump has a practical operating range of 6.3 to 47.3 liters/sec. (100 to 750 gpm), while the effluent pump has an operational range of 3.2 to 20.5 liters/sec. (50 to 325 gpm).

No. 1 Aeration Basin --

The No. 1 aeration basin is a circular mild-steel tank erected above ground; technical data for this unit are summarized in Table 6. Figure 5 indicates the major structural features of interest.

Several different types of mixing and oxygen transfer equipment have been evaluated in this basin. Figure 5 shows the original equipment supplied by Dorr-Oliver, which consisted of an 18.6 kw (25 HP) surface/submerged turbine variable-speed mixer and an 11.2 kw (15 HP) variable-speed air compressor. This system was removed and replaced with Fiscalin equipment.

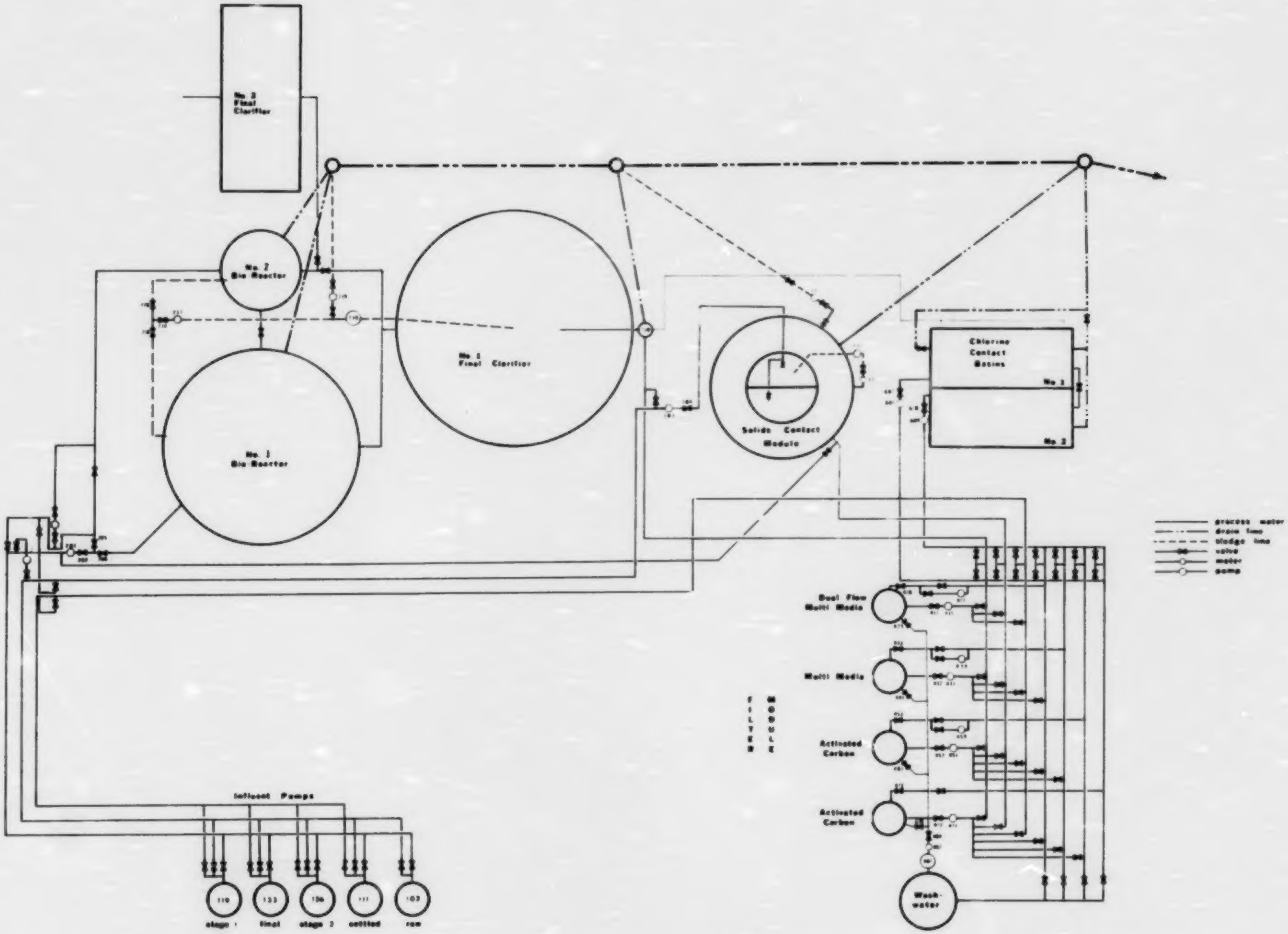
No. 2 Final Clarifier
No. 2 Bio Reactor
No. 1 Bio Reactor
No. 1 Final Clarifier
Solids Contact Module
Chlorine Contact Basins
No. 1
No. 2
Dual Flow Multi Media
Multi Media
Activated Carbon
Activated Carbon
FILTER MODULE
Wash-water
Influent Pumps
110
133
136
111
103
stage 1
final
stage 2
settled
raw
process water
drain line
sludge line
valve
meter
pump

Figure 4. **Dallas Water Reclamation Research Center — Demo Plant**

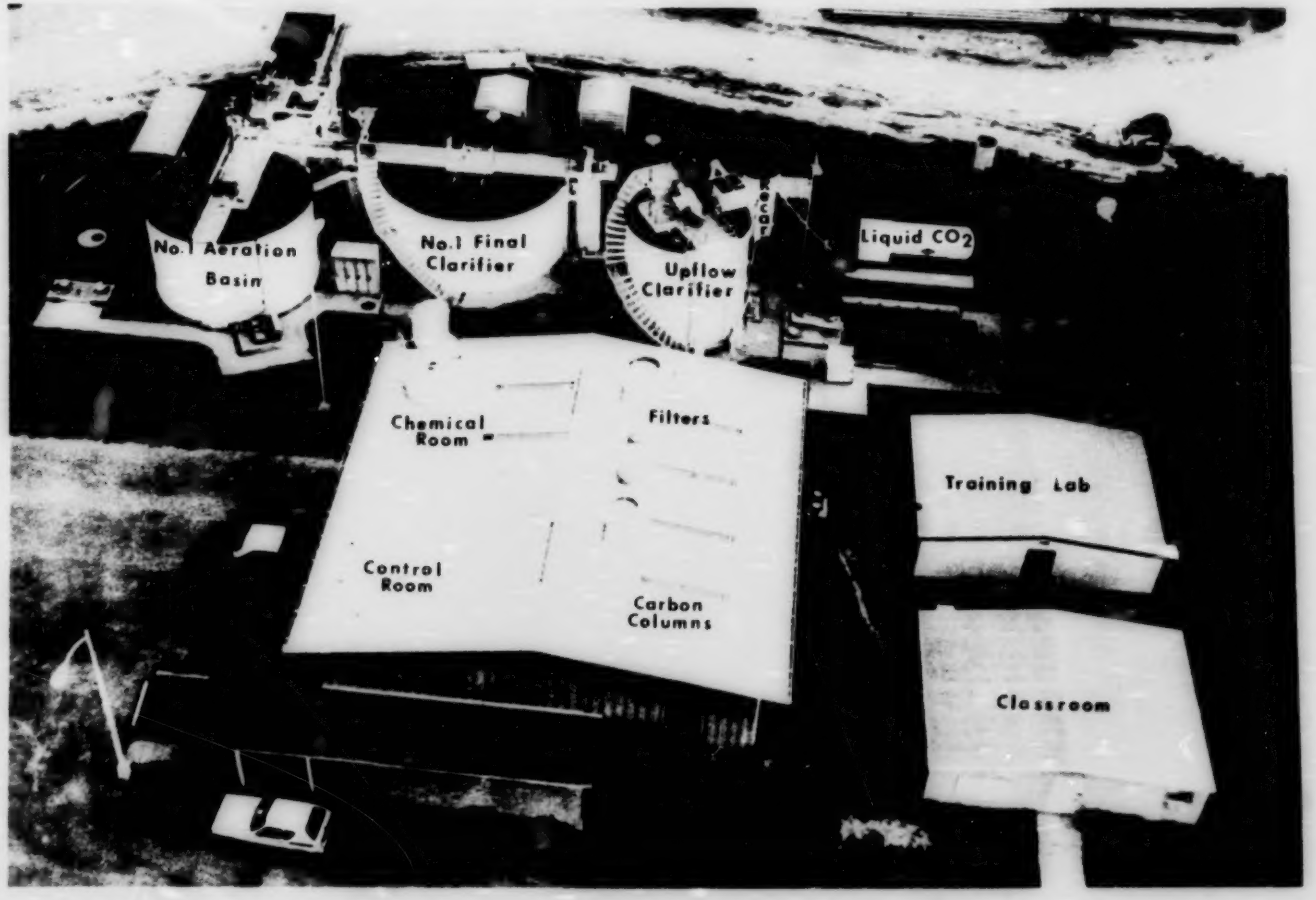
No.1 Aeration Basin
No.1 Final Clarifier
Upflow Clarifier
Recar
Liquid CO2
Chemical Room
Filters
Control Room
Carbon Columns
Training Lab
Classroom

Plate 2. Aerial photograph of Demonstration Plant.

TABLE 6

TECHNICAL DATA FOR THE NO. 1 AERATION BASIN

Diameter = 7.62 m (25.0 ft.)

Depth = 3.66 m (12.0 ft.)

Volume = 170,343 liters (45,000 gal.)

= 560.2 m^3 (6,030 ft.^{3})

Theoretical Residence Time at 6.3 liters/sec (100 gpm) = 7.5 hours

Total Nameplate Power Input = 29.8 kw (40 HP)

Maximum Power Level = 0.053 kw/m^3

= (0.89 HP per 1000 gal)

= (6.64 HP per 1000 ft.^{3})

Air Flow = 118 or 236 liters/sec

= (250 or 500 scfm)

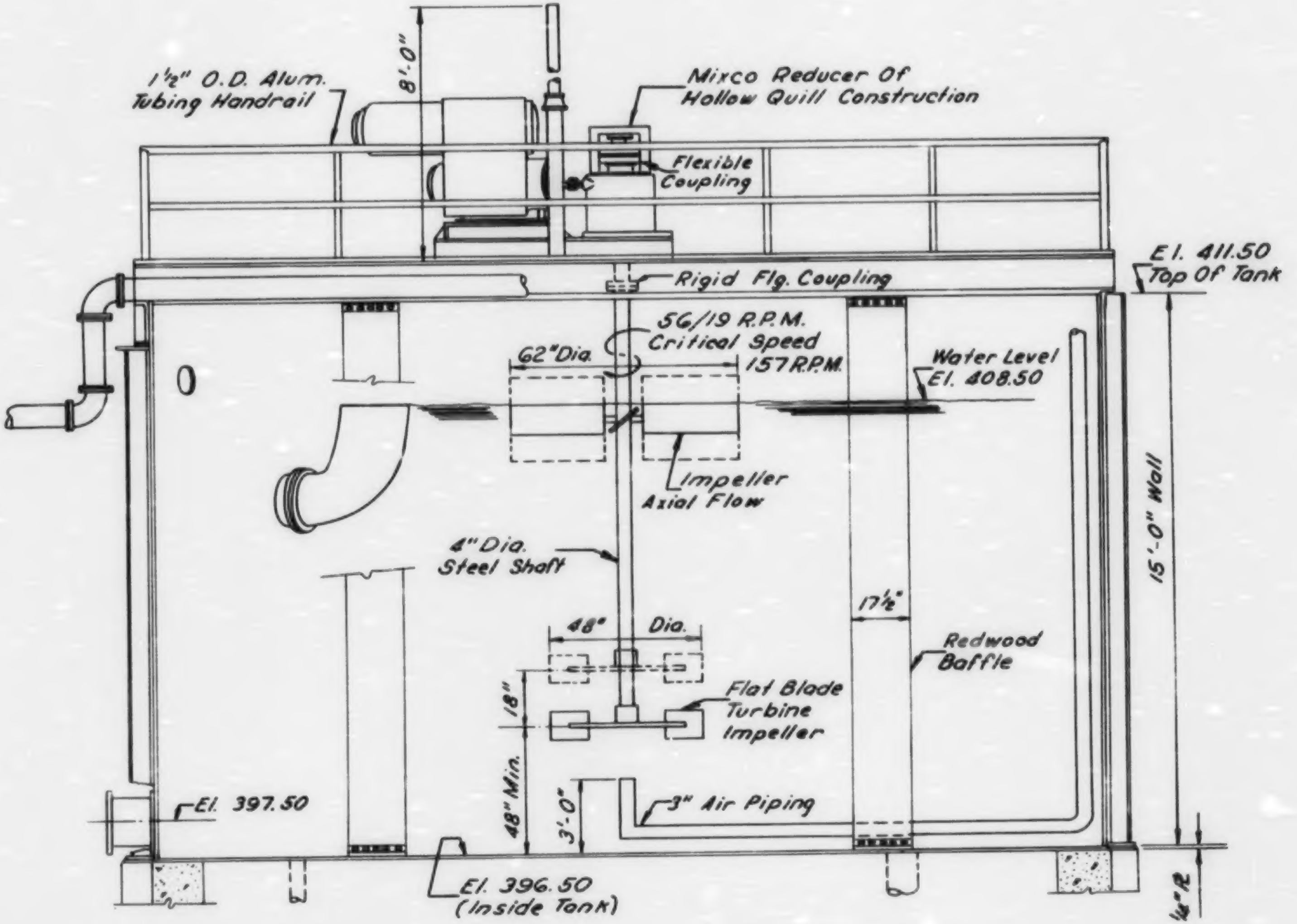
1½" O.D. Alum.
Tubing Handrail
8'-0"
Mixco Reducer Of
Hollow Quill Construction
Flexible
Coupling
E l. 411.50
Top Of Tank
Rigid Flg. Coupling
56/19 R.P.M.
Critical Speed
157 R.P.M.
62" Dia.
Water Level
El. 408.50
Impeller
Axial Flow
4" Dia.
Steel Shaft
15'-0" Wall
17½"
48" Dia.
Redwood
Baffle
18"
Flat Blade
Turbine
Impeller
48" Min.
3'-0"
3" Air Piping
El. 397.50
El. 396.50
(Inside Tank)
¼" R

Figure 5. Elevation of the No. 1 aeration basin.

Aquarius, Inc. is the supplier of the Fiscalin system, which was operated throughout most of the reuse portion of this grant. During the UV phase of this research effort the Aquarius equipment was replaced by a "jet aeration" system manufactured by Penberthy-Houdaille.

No. 1 Final Clarifier

The No. 1 final clarifier is a circular, mild-steel basin erected above ground. As initially provided by Rex Chainbelt, the unit had peripheral feed and square effluent weirs in the center of the tank, as shown in Figure 6. The unit was not originally equipped with a surface skimmer, and the center effluent weir configuration made addition of a skimmer quite complex. Therefore, the basin was modified by removing the center effluent weirs and bolting a new peripheral effluent weir to the inside of the existing influent baffle skirt. A skimmer and scum collector were then fitted to the basin.

Sludge is removed by the head differential between the water surface in the clarifier and the return sludge pump well, via a single armed header. Technical data for this clarifier are presented in Table 7.

No. 2 Activated Sludge System

The No. 2 activated sludge system consists of the 28.4 m^3 (7,500 gal) completely-mixed aeration basin, and a three-hopper Smith and Lovelace final clarifier. The aeration basin has a diameter of 3.14 m (10.3 ft.) and a side water depth of 3.66 m (12.0 ft.). Mixing and oxygen transfer is effected by diffusers, and the maximum air flow is 53.8 liters/sec. (114 scfm).

Upflow Clarifier

An Infilco Densator, shown in Figure 7, is the chemical treatment unit used at the Demonstration Plant. The unit consists of the main tank, 5.5 m in diameter and 5.48 m deep, and an inner cylinder that serves as the rapid mixing and flocculation zones. Influent enters the top of the inner cylinder and the main tank serves as the upflow clarification compartment.

Energy input for mixing and flocculation is supplied via independent turbine-type mixers, each of which is equipped with a U.S. Electric Varidrive that has a 10 to 1 turndown capability.

A 2.54 cm x 10.16 cm (1 in. x 4 in.) steel fluidizer bar is used to prevent the sludge from over compacting. Table 8 summarizes the more significant technical information on the upflow clarifier.

Chemical Storage and Feed Equipment --

Facilities are present at the Demonstration Plant to store and feed the following chemicals.

1. Hydrated lime
2. Hydrated aluminum sulfate

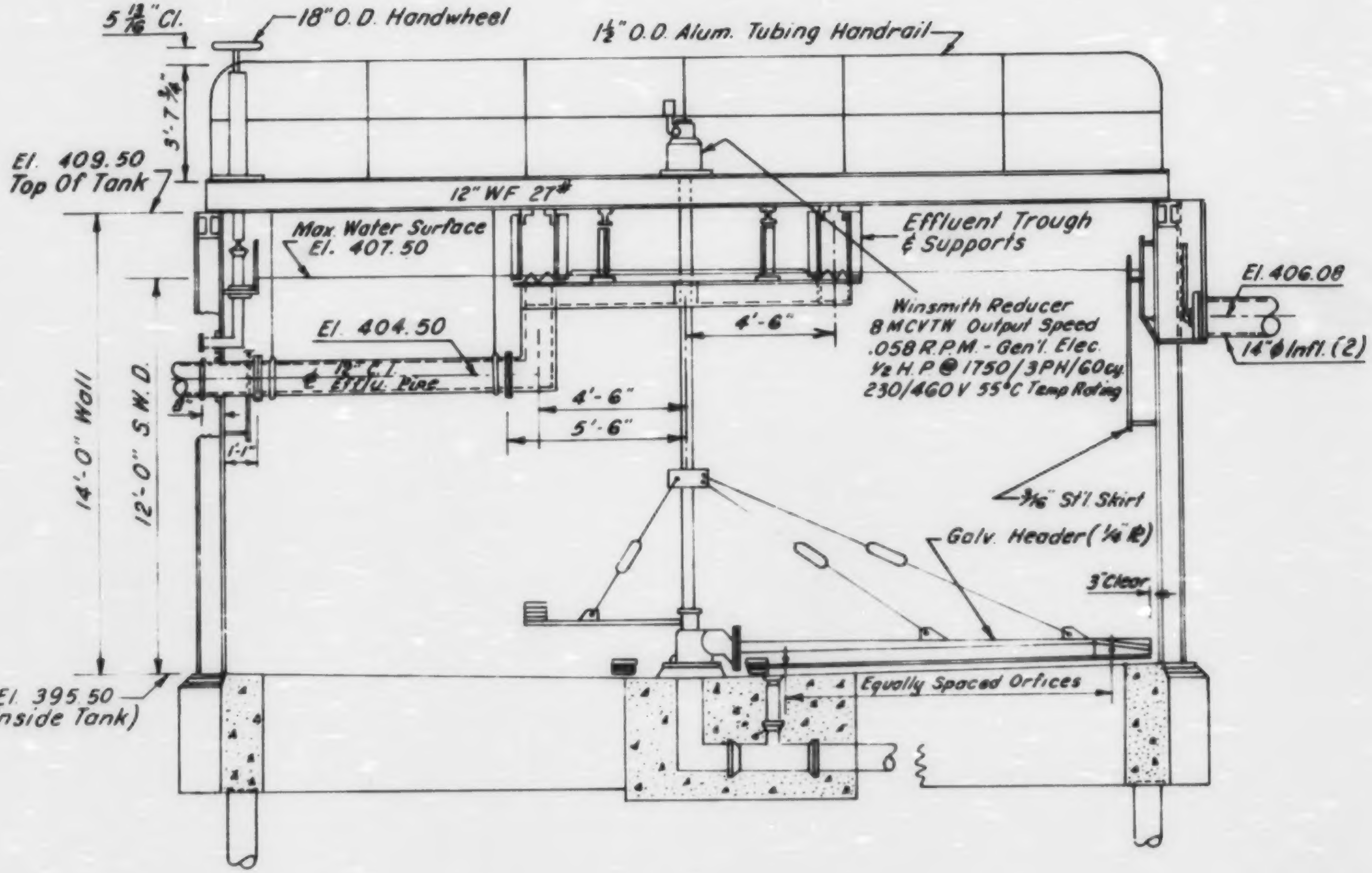
5 13/16" Cl.
18" O.D. Handwheel
1½" O.D. Alum. Tubing Handrail
3'-7¾"
El. 409.50
Top Of Tank
12" WF 27#
Max. Water Surface
El. 407.50
Effluent Trough
& Supports
El. 404.50
12" C.I.
℄ Efflu. Pipe
Winsmith Reducer
8 MCVTW Output Speed
.058 R.P.M. - Gen'l. Elec.
½ H.P @ 1750/3PH/60cy
230/460V 55°C Temp Rating
El. 406.08
14" ϕ Infl. (2)
4'-6"
4'-6"
5'-6"
14'-0" Wall
12'-0" S.W.D.
8"
1'-1"
3/16" St'l. Skirt
Galv. Header (¼" R)
3" Clear
Equally Spaced Orifices
El. 395.50
(Inside Tank)

Figure 6. Elevation of the No. 1 final clarifier.

TABLE 7

TECHNICAL DATA FOR THE NO. 1 FINAL CLARIFIER

Diameter = 9.14 m (30.0 ft.)

Depth = 3.66 m (12.0 ft.)

Volume = 240,373 liters (63,500 gal.)

= 240.4 m^3 (8,480 $ft.^3$)

Surface Area = 65.68 m^2 (707 $ft.^2$)

Weir Length = 27.13 m (89 ft.)

Surface Overflow Rate at 6.3 liters/sec (100 gpm) = 8.50 m^3/m^2/day (203.7 gpd/ft^2)

Weir Loading at 6.3 liters/sec (100 gpm) = 20.09 m^3/m/day (1618 gpd/ft.)

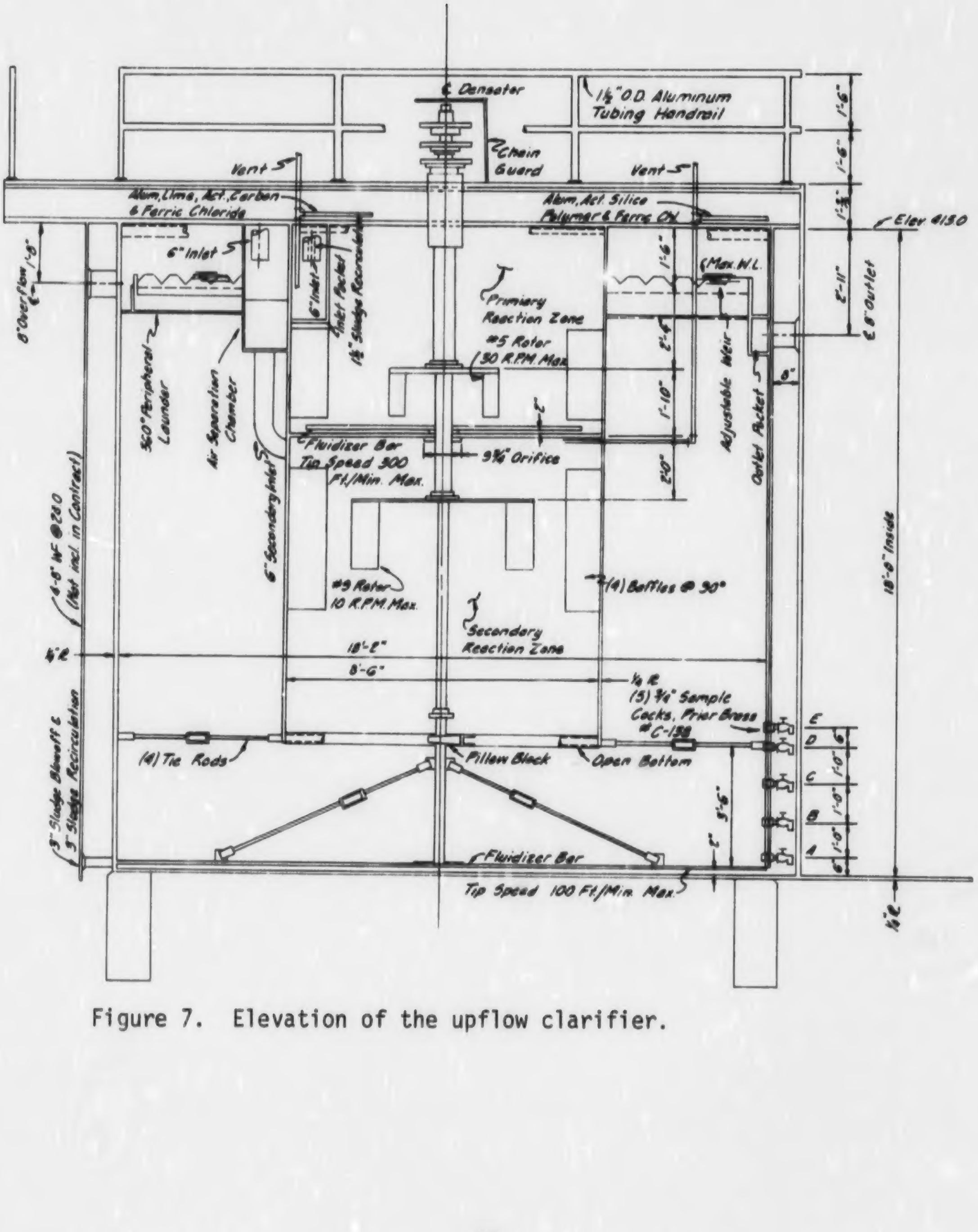
℄ Densator
1½" O.D. Aluminum Tubing Handrail
Chain Guard
Vent
Vent
1'-6"
1'-6"
1'-3"
Elev. 415.0
Alum, Lime, Act. Carbon & Ferric Chloride
Alum, Act. Silica Polymer & Ferric Chl.
6" Inlet
6" Inlet
Inlet Pocket
1½" Sludge Recirculation
8" Overflow 1'-8"
Primary Reaction Zone
#5 Rotor (30 R.P.M. Max.
Max. W.L.
1'-6"
2'-11"
℄ 8" Outlet
2'-4"
1'-10"
2"
2'-0"
Adjustable Weir
Outlet Pocket
8"
360° Peripheral Launder
Air Separation Chamber
6" Secondary Inlet
Fluidizer Bar Tip Speed 300 Ft./Min. Max.
9⅝" Orifice
4-8" WF @ 28.0 (Not incl. in Contract)
#9 Rotor 10 R.P.M. Max.
(4) Baffles @ 90°
Secondary Reaction Zone
18'-0" Inside
½" R
18'-2"
8'-6"
½" R
(5) ¾" Sample Cocks, Prier Brass #C-138
E
D
C
B
A
6"
1'-0"
1'-0"
1'-0"
6"
3" Sludge Blowoff & 3" Sludge Recirculation
(4) Tie Rods
Pillow Block
Open Bottom
5'-6"
2"
Fluidizer Bar
Tip Speed 100 Ft./Min. Max.
½" R

Figure 7. Elevation of the upflow clarifier.

TABLE 8

TECHNICAL DATA FOR THE UPFLOW CLARIFIER

Rapid Mixing Zone		
Diameter	=	2.59 meters (8.5 ft.)
Depth	=	0.64 meters (2.1 ft.)
Surface Area	=	5.26 sq.m. (56.6 sq.ft.)
Volume	=	3.35 cu.m. (886 gal.)
Residence time at 6.31 liters/sec (100 gpm)	=	8.86 min.
Mixing	=	3 to 30 rpm
Flocculation Zone		
Diameter	=	2.59 meters (8.5 ft.)
Depth	=	3.29 meters (10.8 ft.)
Volume	=	17.3 cu.m. (4,570 gal.)
Residence time at 6.31 liters/sec (100 gpm)	=	45.7 min.
Mixing	=	1 to 10 rpm
Upflow Clarification Zone		
Outside diameter	=	5.54 meters (18.167 ft.)
Inside diameter	=	2.59 meters (8.5 ft.)
Volume	=	96.8 cu.m. (25,580 gal.)
Surface Area	=	18.71 sq.m. (201.4 sq.ft.)
Overflow rate at 6.31 liters/sec (100 gpm)	=	29.9 m^3/m^2/day (717 gpd/sq.ft.)
Weir loading at 6.31 liters/sec	=	33.5 m^3/m/day (2,700 gpd/ft)
Residence time at 6.31 liters/sec	=	255.8 min.
Total theoretical residence time at 6.31 liters/sec (100 gpm)	=	7 hours

3. Ferric chloride
4. Dry polyelectrolytes
5. Liquid polyelectrolytes
6. Activated silica
7. Powdered activated carbon
8. Chlorine

All coagulants and coagulant aids, with the exception of lime, can be fed to either aeration basin or final clarifier, to the upflow clarifier, or in front of the filters or carbon contactors for use as filtration aids. The lime slurry can be pumped to either of the activated sludge systems or the upflow clarifier.

No. 1 Mixed-Media Filter --

The No. 1 filter is shown in Figure 8 as it was initially installed at the Demonstration Plant. At that time the filtering media consisted of 0.91 meters (3.0 feet) of sand overlayed with 0.30 meters (12 inches) of anthracite. The influent flow was split equally between the top and bottom of the filter bed, and the effluent was withdrawn through a mid-bed collector located 15 cm (6 inches) below the sand-anthracite interface. The filter performance can be characterized as having been generally good; however, structural deficiencies with the mid-bed collector resulted in frequent maintenance and the unit was converted to a conventional gravity flow filter.

When the filter was rebuilt media supplied by Neptune Microfloc was utilized and the media specifications are summarized in Table 9. The filter has a nominal diameter of 1.2192 meters (4.0 feet) and a surface area of 1.17 sq.m. (12.57 sq.ft.). At a flow of 2.37 liter/sec. (37.5 gpm) the filtration rate is 174.7 cu.m. per sq.m. per day (3 gpm/sq.ft.). Filter backwashing is conventional and utilizes a surface wash in lieu of an air scrub.

No. 2 Dual-Media Filter --

Structually, the No. 2 filter is almost identical to the No. 1 filter, and this unit is also operated in the conventional gravity-flow mode. Media consist of 30.48 cm (12 inches) of sand with a 60.96 cm (24 inches) anthracite cap. The filter sand has an effective size of 0.57 mm and a uniformity coefficient of 1.6. Air scour is normally used prior to backwash at a rate of 20.2 liters per sec. per sq.m. (4 scfm per sq.ft.).

Activated Carbon Contactors

Both the No. 3 and the No. 4 columns at the Demonstration Plant serve as granular activated carbon contactors, and construction details are shown in Figure 9. Both units are 1.22 meters (4.0 feet) in diameter and use a

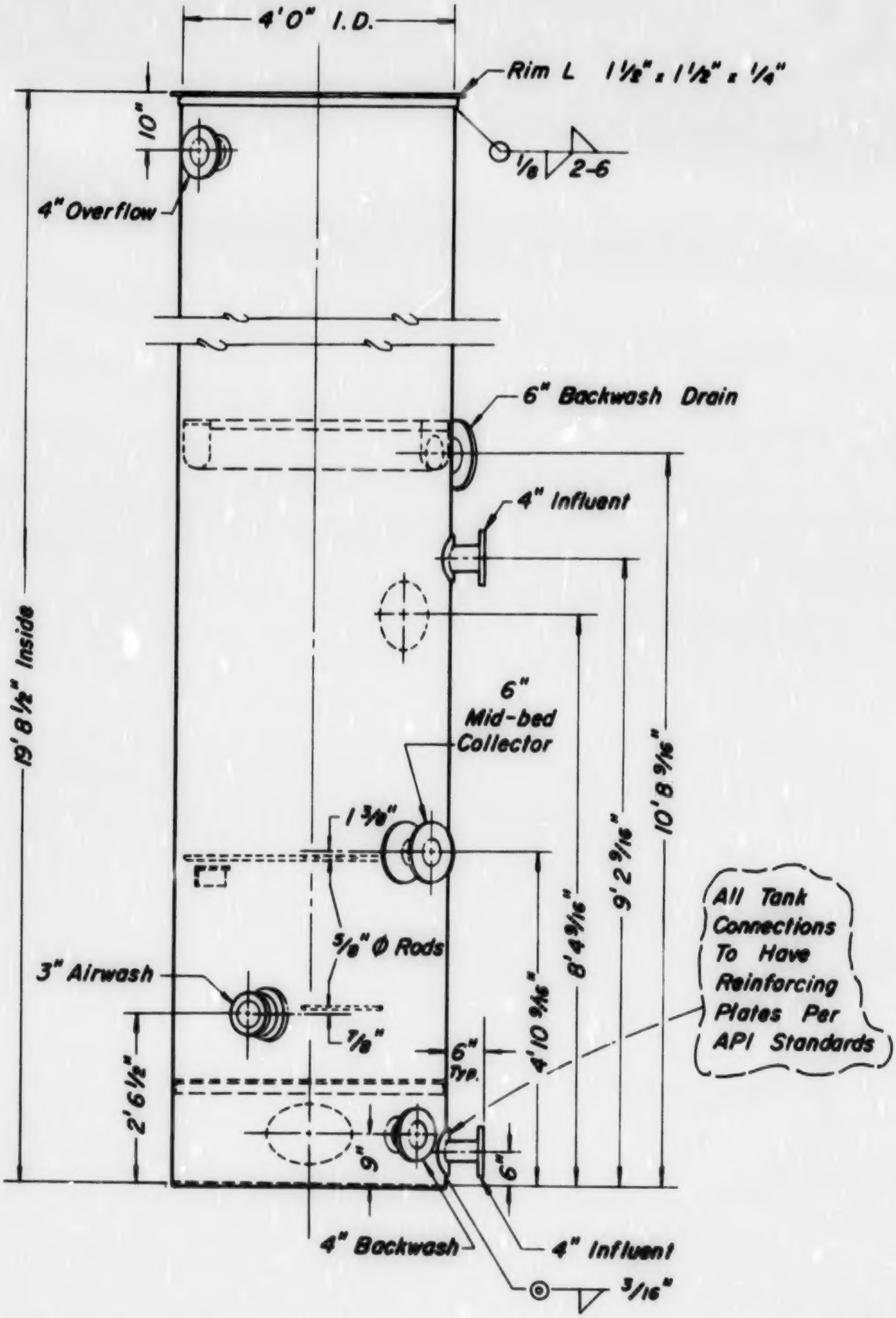
4'0" I.D.
Rim L 1½" x 1½" x ¼"
1/8 2-6
10"
4" Overflow
19'8½" Inside
6" Backwash Drain
4" Influent
6"
Mid-bed
Collector
1 3/8"
5/8" Ø Rods
3" Airwash
7/8"
6"
Typ.
2'6½"
9"
6"
4'10 9/16"
8'4 9/16"
9'2 9/16"
10'8 9/16"
All Tank
Connections
To Have
Reinforcing
Plates Per
API Standards
4" Backwash
4" Influent
3/16"

Figure 8. Typical elevation of the No. 1 and No. 2 gravity filters.

TABLE 9

MEDIA SPECIFICATIONS FOR THE NO. 1 MIXED-MEDIA FILTER

Material	Size	Depth	Effective Size	Uniformity Coefficient
Gravel	1.905 to 1.27 cm (3/4 to 1/2 in.)	7.62 cm (3 in.)		
	1.27 to 0.635 cm (1/2 to 1/4 in.)	7.62 cm (3 in.)		
	<0.635 cm (<1/4 in.)	5.08 cm (2 in.)		
Garnet				
Coarse, MS-11		7.62 cm (3 in.)	0.87 mm	1.17
Fine, MS-7		11.43 cm (4.5 in.)	0.27 mm	1.22
Sand, MS-18		24.13 cm (9.5 in.)	0.41 mm	1.32
Anthracite, MS-19		55.88 cm (22 in.)	1.05 mm	1.35

Total Depth of Filter Media = 99.06 cm (39 inches)

3.048 meter (10.0 foot) charge of carbon, or 1998 kg (4396 lbs.) at a bulk density of 0.56 kg per liter (35 lbs. per cu. ft.). The carbon contactors use the same air scrubbing system for backwashing as the No. 2 filter. Calgon Filtrasorb 400, 8x30 mesh, was used throughout the study.

Chlorine Contact Basins

The Demonstration Plant has two chlorine contact basins which may be operated in parallel or in series. Each basin is 5.49 meters (18.0 feet) long, 2.26 meters (7.41 feet) wide, and 0.48 meters (1.58 feet) deep. Each basin has a volume of 5.95 cu.m. (1573 gal.), which results in a theoretical residence time of 15.7 minutes at a flow of 6.31 liters per sec. (100 gpm). Eleven fiberglass baffles were installed in each basin, such that plug flow would be closely approximated. Dye studies have been used to quantify the hydraulic characteristics of the end-around baffling system, and observed residence time distribution functions closely approximate theoretical values. The chlorination equipment is capable of a maximum feed of 22.7 kg (50 lbs.) of chlorine per day.

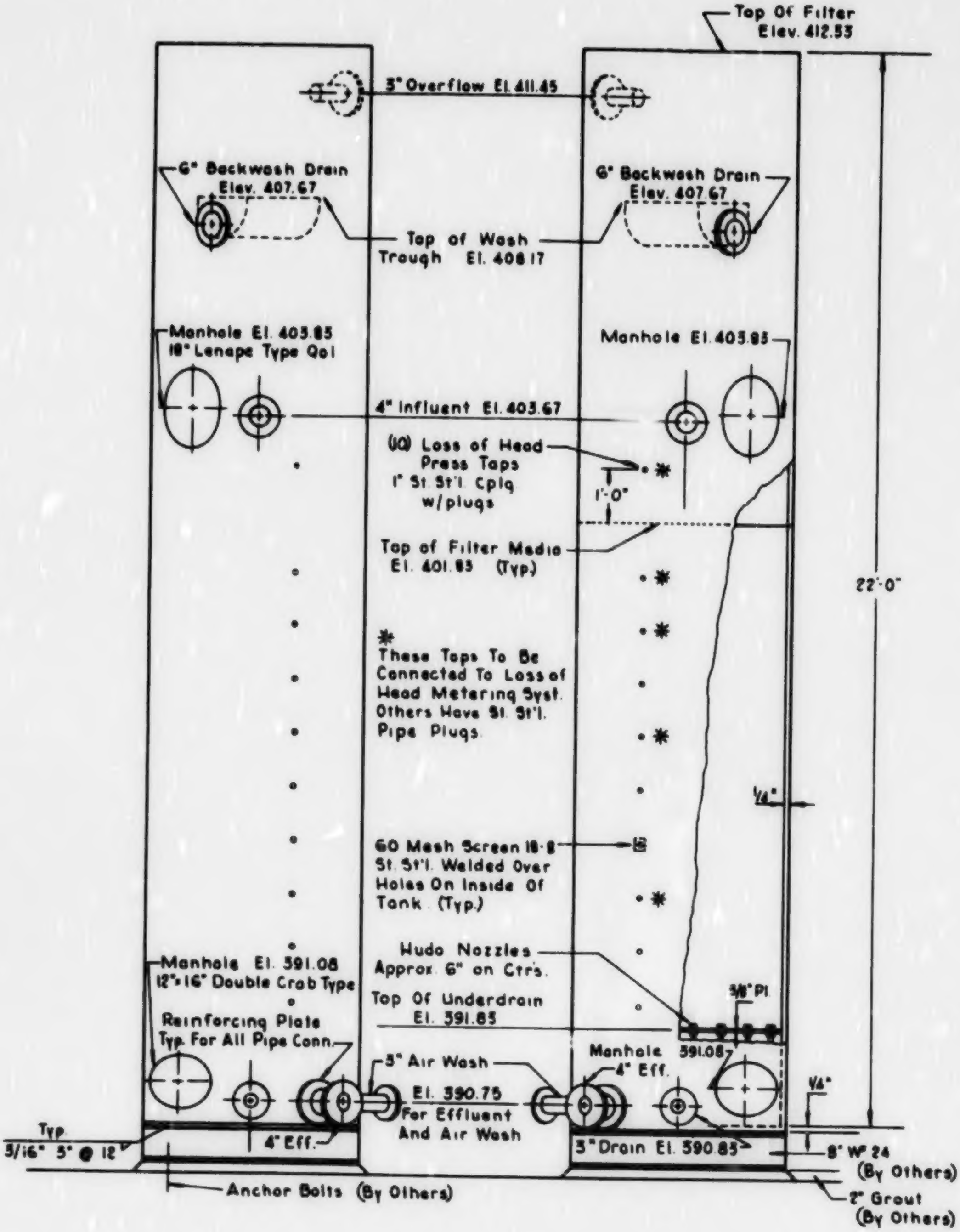
Top Of Filter Elev. 412.53
3" Overflow El. 411.45
6" Backwash Drain Elev. 407.67
6" Backwash Drain Elev. 407.67
Top of Wash Trough El. 408.17
Manhole El. 403.85 18" Lenape Type Qol
Manhole El. 403.85
4" Influent El. 403.67
(10) Loss of Head Press Taps 1" St. St'l. Cplg w/plugs
1'-0"
Top of Filter Media El. 401.83 (Typ.)
22'-0"
* These Taps To Be Connected To Loss of Head Metering Syst. Others Have St. St'l. Pipe Plugs.
1/4"
60 Mesh Screen 18-8 St. St'l. Welded Over Holes On Inside Of Tank (Typ.)
Hudo Nozzles Approx. 6" on Ctrs.
Top Of Underdrain El. 391.83
3/8" Pl
Manhole El. 391.08 12"×16" Double Crab Type
Reinforcing Plate Typ. For All Pipe Conn.
3" Air Wash
Manhole 391.08
4" Eff.
El. 390.75 For Effluent And Air Wash
1/4"
Typ. 3/16" 5" @ 12"
4" Eff.
3" Drain El. 590.83
8" W 24 (By Others)
Anchor Bolts (By Others)
2" Grout (By Others)

Figure 9. Elevation of downflow granular activated carbon contactors.

SECTION V

SAMPLING AND ANALYTICAL PROCEDURES

SAMPLING PROCEDURES

The sampling procedures described below were utilized for the duration of this research effort. Samples for routine wet chemistry and metals analyses were collected by the operators on duty at the Demonstration Plant, while samples for microbiological analyses were collected by the staff microbiologist or microbiology laboratory assistants.

Routine Chemistry Samples

Samples for routine wet chemistry analyses were collected by the plant operators seven days a week at 1 AM, 5 AM, 9 AM, 1 PM, 5 PM, and 9 PM. Wide-mouth, half-pint plastic bottles were used for sample collection. These sample bottles were placed in a refrigerator until transported to the laboratory, at which time they were composited by the staff chemists. Since the Demonstration Plant was operated at hydraulic steady-state, equal volumes (400 ml) of each of the six grab samples were used for the 24-hour composite sample.

Metals Samples

Samples for metals determinations were collected by the plant operators at the same time samples for routine analyses were collected. Four hundred milliliter fractions were composited in one-gallon amber bottles to which redistilled nitric acid (10 ml per liter) had been previously added for sample preservation.

Microbiological Samples

Either the staff microbiologist or the microbiology laboratory technicians collected all samples for microbiological evaluation. The samples were collected in 125 ml, wide-mouth glass bottles with glass stoppers that had been previously dry sterilized at 350°F for one hour.

ANALYTICAL PROCEDURES

The analytical procedure used in this research effort followed the *13th Edition of Standard Methods for the Examination of Water and Wastewater* in so far as practicable (5).

Flow

The influent flows to all unit processes, with the exception of the recarbonation basin, were measured by BIF/Brooks magnetic flow meters. This combination of meters and recorders proved to be unreliable, and the City's instrumentation technicians lacked the expertise necessary to keep the flow meters properly calibrated and maintained. These problems resulted in the installation of several physical flow measuring elements (orifices, weirs, and venturi sections) such that accurate flow measurements could be obtained.

Biochemical Oxygen Demand

The procedure used for determining the five-day biochemical oxygen demand was as given in Section 219 of Standard Methods, and the dilution technique described in paragraph 4 (ii) was utilized.

Chemical Oxygen Demand

The following procedures were utilized to determine COD values on the routine samples. The low level technique was employed for those samples where the COD was expected to be less than 50 mg/1.

High Level Technique

The procedure used was as described in Section 220 of Standard Methods.

Low Level Technique -

The COD of low level samples was determined by using the procedure given on page 19 of Methods for Chemical Analyses of Water and Wastes 1971 (6). Two modifications were made to the procedure. The amount of mercuric sulfate was reduced from 1.0 to 0.4 grams, and the ferrous ammonium sulfate solution was 0.01 N instead of 0.025 N.

Total Organic Carbon

All total organic carbon determinations were made using a Beckman Model 915 Total Organic Carbon Analyzer.

Total Residue

Total solids determinations were made in accordance with the procedure in Section 224A of Standard Methods.

Nonfiltrable Residue

Total suspended solids determinations were made by employing the procedure in Section 224C of Standard Methods and using 2.4 cm diameter glass-fiber filters and Gooch crucibles.

Total Dissolved Solids

Total dissolved solids were computed by subtracting the nonfiltrable residue from the total residue.

Total Phosphorus

The single reagent method given in *Methods for Chemical Analyses of Water and Wastes 1971* was used for all total phosphorus determinations. The amount of ammonium persulfate used was increased from 0.4 to 0.5 grams, and the amount of combined reagent was increased from 8 ml to 10 ml.

Ammonia Nitrogen

Ammonia nitrogen determinations were made by using an ion-specific electrode and the Known Addition Method (7). The electrode used was an Orion Model 95-10.

Total Kjeldahl and Organic Nitrogen

Total Kjeldahl nitrogen was determined by using an ion-specific electrode and the Known Addition Method after completing the digestion phase of the procedure given in Section 216 of *Standard Methods*. Organic nitrogen was determined by subtracting the ammonia nitrogen from the total Kjeldahl nitrogen.

Nitrite Nitrogen

Nitrite nitrogen determinations were made using the procedure described in Section 134 of *Standard Methods*.

Nitrate Nitrogen

The phenoldisulfonic acid method, Section 213D of *Standard Methods*, was used to determine combined nitrite-nitrate nitrogen. Nitrate nitrogen was computed by subtraction of the nitrite nitrogen.

Sulfate

Sulfate was determined by an indirect atomic absorption spectroscopy method by adding a known concentration of barium chloride to form a barium sulfate precipitate. The barium concentration in solution was then determined by atomic absorption, and the sulfate concentration determined by subtraction.

Chloride

Chloride concentrations were determined by the mercuric nitrate method described in Section 112B of *Standard Methods*.

Silica

Silica determinations were made using the molybdate method presented in *Methods for Chemical Analyses of Water and Wastes 1971*.

Alkalinity

Total and phenolphthalein alkalinity was determined by using the procedures given in Section 102 of *Standard Methods* using methyl orange.

Turbidity

Turbidity was determined by the nephelometric method described in Section 163A of *Standard Methods* with a Hach Model 2100A Turbidimeter. The standard references were formazin polymer suspensions.

Color

Color determinations were made by plant operators using a Hellige Aqua Tester and platinum-cobalt color disk.

Metals Determinations

Samples for metals analyses were filtered through a glass fiber filter and then concentrated by a factor of ten. Concentration was accomplished by heating (below the boiling point) a 500 ml sample until the volume was reduced to less than 50 ml, and then making up to volume in a 50 ml volumetric flask.

Atomic Absorption -

Atomic absorption spectroscopy was utilized to determine the concentrations of aluminum, barium cadmium, calcium,cobalt, copper, chromium, iron, lead, magnesium, manganese, silver, strontium, and zinc. A Perkin-Elmer Model 403 was used for these analyses, and standard procedures given in the *Perkin-Elmer Operator's Manual* (8) and *Standard Methods* were employed.

Flame Emission -

Sodium and potassium concentrations were determined by flame emission spectrophotometry by operating the P-E 403 in that mode, and using methods given in *Standard Methods*.

Arsenic -

Arsenic concentrations were determined by using the silver diethyldithiocarbamate method presented in Section 104A of *Standard Methods*.

Boron -

The curcumin method given in Section 107A of *Standard Methods* was used to determine boron concentrations, with an ion-exchange modification to remove cationic interferences.

Beryllium -

The morin fluorometric method (9) was employed for beryllium determinations.

Mercury -

Mercury concentrations were determined by the flameless atomic absorption method with a Perkin-Elmer Model 209B atomic absorption spectrophotometer.

Molybdenum -

The dithiol method of Brown, et al.(10) was used to determine molybdenum concentrations.

Selenium -

Selenium concentrations were determined by employing the diaminobenzidine method given in Section 150A of Standard Methods.

Silica -

Silica determinations were made by using the heteropoly blue method given in Section 151C of Standard Methods.

Vanadium -

The catalytic oxidation method presented by Brown, et al.(U.S. Geological Survey) was used to determine vanadium concentrations (10).

Sampling Frequency -

The sampling frequency used during the project period is shown in Table 10. Most of the more conventional water quality parameters that had process control significance were evaluated daily and on 24-hour composite samples. Those parameters necessary for general background information, such as chlorides and sulfates, were evaluated on weekly composite samples. Due to time and cost limitations, trace element determinations were made on weekly composite samples.

TABLE 10

PROPOSED SCHEDULE OF ANALYSES

Parameter	Raw Sewage	A.S. influent	A.S. Effluent	Upflow Clarifier Effluent	Multi-Media Filter Effluent	Carbon Column Effluent	Final Chlorinated Effluent
Chlorides			WC			WC	WC
Sulfates			WC		WC		WC
Alkalinity		DC & 4P	DC & 4P				DC
Dissolved Solids			WC			WC	WC
Nitrates		DC	DC	DC	DC		DC
Nitrites		DC	DC	DC	DC		DC
Ammonia		DC	DC	DC	DC		DC
Hardness		WC	WC				WC
Total P		DC	DC				WC
Trace Elements		WC	WC		WC		WC
COD	MPR	DC	DC	DC	DC	DC	DC
TOC		DC	DC	DC	DC	DC	DC
BOD	MPR						4M(DC)
Turbidity				DC	DC	DC	DC
Color				DC	DC	DC	DC
Suspended Solids	MPR	DC	DC	DC	DC	DC	DC
Temperature		D	D				D
pH		DC	DC		DC		DC
Conductivity		DC	DC				DC
Total Coliforms			D				D
Fecal Coliforms			D				D

Sample Frequency:

MPR = Municipal Plant Records
D = Daily Grab
DC = Daily 24 Hr. Comp.
2M = Twice Monthly

W = Weekly Grab
WC = Weekly Comp.
4M = 4 Times Per Month
4P = 4 Hrs. @ Plant

SECTION VI

PLANT OPERATION AND PERFORMANCE

The Demonstration Plant of the Dallas Water Reclamation Research Center was configured as shown in Figure 10 for the potable reuse research effort discussed in this report. The basic process control philosophy was to produce as high a quality product water as possible by operating the completely-mixed activated sludge system to nitrify, maintaining a pH of at least 11.3 in the upflow clarifier, and employing extended empty-bed contact time by utilizing two granular activated carbon contactors in series operation.

The primary coagulant fed to the upflow clarifier was hydrated lime with a minimal dose of ferric chloride used as a flocculation aid. Single-stage recarbonation of the high pH effluent from the upflow clarifier was accomplished by using liquid carbon dioxide. Two-stage recarbonation with intermediate clarification would have reduced the calcium in the product water and been much more desirable; however, these facilities were not available at the Demonstration Plant.

The recarbonated water was then pumped to the No. 1 mixed-media filter, which is a conventional gravity-flow filter with Neptune Microfloc media and a rate of flow controller on the influent line. Both granular activated carbon contactors were operated in series, with the trailing (No.3) contactor being loaded with virgin carbon. The final effluent was then disinfected with a chlorine solution in the chlorine contact basin.

Table 11 presents a brief summary of the performance of the Demonstration Plant during this research effort. All values reported are arithmetic means for the study period; the raw wastewater data were obtained from the monthly reports of the Wastewater Treatment Division, Dallas Water Utilities Department.

The plant performance was excellent during most of the project period, as the effluent quality indicates. Nitrification was not complete, since an average of 2.6 mg/l of ammonia nitrogen was present in the final product water; however, the total nitrogen removal approached seventy-two percent with only 9.1 mg/l of nitrogen being found in the product water. The Demonstration Plant has no nitrogen removal process per se, and this significant reduction in total nitrogen was not anticipated.

The observed reductions in gross organic materials as measured by the five-day BOD test and COD test were about as anticipated except that the average product water COD concentration of 3.3 mg/l is somewhat lower than one might predict.

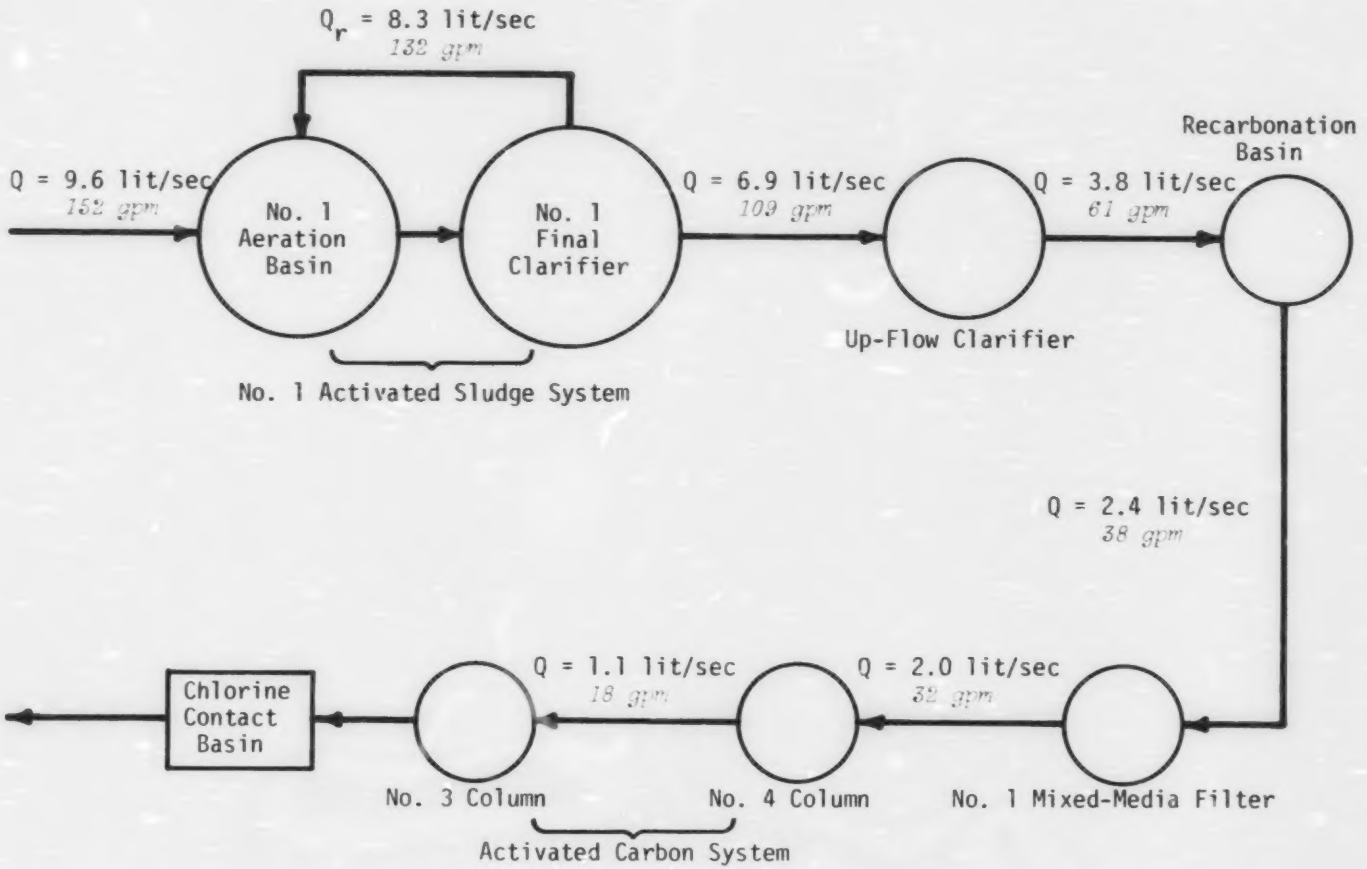
Q_r = 8.3 lit/sec
132 gpm
Q = 9.6 lit/sec
152 gpm
No. 1 Aeration Basin
No. 1 Final Clarifier
No. 1 Activated Sludge System
Q = 6.9 lit/sec
109 gpm
Up-Flow Clarifier
Q = 3.8 lit/sec
61 gpm
Recarbonation Basin
Q = 2.4 lit/sec
38 gpm
No. 1 Mixed-Media Filter
Q = 2.0 lit/sec
32 gpm
No. 4 Column
Q = 1.1 lit/sec
18 gpm
No. 3 Column
Activated Carbon System
Chlorine Contact Basin

Figure 10. Demonstration Plant configuration for the potable reuse study.

TABLE 11

SUMMARY OF DEMONSTRATION PLANT PERFORMANCE

Parameter	Raw Wastewater (mg/1)	AWT Effluent (mg/1)	Reduction (percent)
TSS	212	2	99.1
BOD_5	198	1.3	99.3
COD	442	3.3	99.3
UOD*	375	14	96.3
NH_3-N	16.9	2.6	84.6
Org.N	14.6	0.6	95.9
NO_2-N	0.0	0.16	---
NO_2,&NO_3-N	0.5	5.9	---
Total N	32.0	9.1	71.6
Total P	12.6	0.4	96.8
pH	7.1	6.9	---

*Ultimate Oxygen Demand = 1.5 (BOD_5) + 4.6 (NH_3-N)

Product water total suspended solids (TSS) averaged 2 mg/l, which is well below the practical working limit of the procedure.

COMPLETELY-MIXED ACTIVATED SLUDGE

The completely-mixed activated sludge system was operated at an average flow of 9.6 liters per second (152 gpm) during this study. The influent, pumped from the White Rock STP, was effluent from the primary clarifiers during most of the project, although alternate influent sources were used on some occasions. The performance of the completely-mixed activated sludge system is summarized in Table 12, which presents arithmetic means for the various water quality parameters. Geometric means have been reported for total plate counts (TPC/ml), total coliforms (TC/100 ml), and fecal coliforms (FC/100 ml).

The treatment obtained by the biological process was about what one would expect for a conventional activated sludge system treating a "typical municipal wastewater". Effluent total suspended solids averaged 22 mg/l for the study period, which represents an observed reduction of approximately 90 percent. An equivalent reduction in gross organic compounds, as measured by COD and TOC,was observed.

Nitrification was the major process control criterion for the activated sludge system during this study. The effluent ammonia nitrogen concentration averaged 3.7 mg/l for the study, representing an ammonia nitrogen reduction of 78.1 percent, which exactly coincides with the observed total Kjeldahl nitrogen reduction. The combined effluent nitrite-nitrate nitrogen concentration was considerably lower than expected, averaging 6.5 mg/l. The low concentration of oxidized forms of nitrogen resulted in a total nitrogen reduction by biological treatment of 58.1 percent, which is higher than one would normally predict.

An alkalinity decrease of 76 mg/l (as $CaCO_3$) resulted from nitrification in the activated sludge system, which represents an observed alkalinity decrease of 6.5 mg/l for each 1.0 mg/l of ammonia nitrogen oxidized. The factor of 6.5 compares favorably with the theoretical value of 7.2 mg/l of alkalinity destroyed per mg/l of ammonia nitrogen oxidized. However, when the observed alkalinity reduction is compared with nitrate production the ratio is 12.3. This is much higher than theory predicts, and when evaluated in terms of the high observed total nitrogen removal, the conclusion is that very significant denitrification must have occurred in the secondary clarifier.

Table 13 summarizes the hydraulic process control parameters for the completely-mixed activated sludge system, and the facility operation must be considered conservative when considering these parameters. The theoretical residence time in the secondary clarifier of 6.9 hours is longer than normally encountered, and does provide an opportunity for uncontrolled denitrification to occur.

Process control parameters for the activated sludge system are summa-

TABLE 12

PERFORMANCE SUMMARY OF THE COMPLETELY-MIXED ACTIVATED SLUDGE SYSTEM

PARAMETER	RAW WASTEWATER (mg/1)	A.S. INFLUENT (mg/1)	A.S. EFFLUENT (mg/1)	REDUCTION (percent)
SS	212	124	22	89.6
COD	442	281	44	90.0
TOC	148	*39.2	*11.3	92.4
NH_3-N	16.9	15.4	3.7	78.1
Org.N	14.6	15.4	3.2	78.1
TKN	31.5	24.1	6.9	78.1
NO_2 & NO_3-N	0.5	0.3	6.5	--
Total N	32.0	24.4	13.4	58.1
Total P	12.6	8.7	6.0	52.4
pH	--	7.1	7.3	--
Alkalinity	--	228	152	33.3
Hardness	--	188	176	--
TPC/ml	--	3.9×10^6	2.1×10^5	94.2
TC/100 ml	--	1.4×10^8	9.1×10^5	99.3
FC/100 ml	--	8.5×10^6	1.3×10^5	98.5
F^-	--	1.26	1.27	--
NaCl	--	--	100	--
SO_4	--	--	94	--
TDS	--	--	496	--

*Soluble TOC

TABLE 13

HYDRAULIC PROCESS CONTROL PARAMETERS FOR THE COMPLETELY-MIXED ACTIVATED SLUDGE SYSTEM

Q	=	9.59 liters/sec 152 gpm
Q_r	=	8.33 liters/sec 132 gpm
Q Wastes	=	4478 liters/day 1183 gpd
T	=	4.9 hours
$T(Q+Q_r)$	=	2.6 hours
Clarifier T	=	6.9 hours
Clarifier $T\ (Q+Q_r)$	=	3.7 hours
Overflow Rate	=	$12.6 m^3/day/m^2$ $310\ gpd/ft^2$
Weir Loading	=	$29.8\ m^3/day/m^2$ $310\ gpd/ft^2$

rized in Table 14. Mixed liquor suspended solids averaged 2723 mg/l during the study period, and the average MLVSS to MLSS ratio was 0.83. The return activated sludge (RAS) concentration averaged 5858 mg/l, which is much lower than one would encounter under "normal" operation. The return sludge flow meter at the pilot plant does not register at flows less than about 6.2 liters per second (100 gpm) and a relative high recycle ratio of 0.87 was used in order to obtain a reading on the return sludge flow meter. The high recycle ratio clearly reduced the return sludge concentration.

The average food to microbe ratio and sludge age for the study period were 0.50 kg COD applied / day / kg MLSS and 10.4 days, respectively. Both values are approximately sufficient for maintaining nitrification in moderate temperatures. Monthly average wastewater temperatures ranged from a high of 29°C during July 1974 to a low of 18.3°C during December 1974 and January 1975. The average wastewater temperature for the project period was 24.2°C.

Figure 11 presents time-series plots of the mixed liquor suspended solids concentration and the seven-day, moving-average sludge age. The MLSS concentration fluctuated about the mean of 2723 mg/l only slightly through November 1974. However, in early December a major process upset occurred when one of the plant operators left the waste sludge valve open for his entire shift. The result was a decrease in MLSS from 3300 mg/l to about 400 mg/l.

The loss of solids from the system produced a commensurate decrease in sludge age, and very poor treatment. In order to rebuild the MLSS as quickly as possible, ferric chloride feed was switched from the upflow clarifier to the aeration basin of the activated sludge system. During the period of December 7 to 31, 1974 an average ferric chloride dose of 27 mg/l was fed to the aeration basin; additionally, no sludge was wasted during this time.

The aeration basin dissolved oxygen concentration and dissolved oxygen uptake rates measured in the mixed liquor and return sludge are shown in Figure 12. During most of the project period the oxygen transfer equipment provided by Aquarius, Inc. functioned well, and sufficient residual dissolved oxygen was present in the aeration basin to prevent the nitrifying system from becoming oxygen limited. The Aquarius equipment was removed for maintenance from August 13 to August 25, 1974, and during that time mixing and oxygen transfer was maintained by utilizing four temporary air diffusers. The performance of the diffusers was less than optimum, and the process was oxygen limited with respect to nitrification.

The Aquarius equipment suffered a major break-down on December 21, 1974 and from then until the termination of this project the activated sludge system operated with the stand-by diffusers providing oxygen transfer.

The plant operators performed uptake rate determinations on both the mixed liquor and return sludge every six hours. The average dissolved oxygen uptake rate measured in the mixed liquor was 25.1 mg-hr/l for this study. Considerable variability in oxygen demand is evident in Figure 12. Peak oxygen demands of 66 mg-hr/l were measured, and this value represents

TABLE 14

PROCESS CONTROL PARAMETERS FOR THE COMPLETELY-MIXED ACTIVATED SLUDGE SYSTEM

MLSS = 2723 mg/l

MLVSS = 2271 mg/l

MLVSS/MLSS = 0.83

RAS = 5858 mg/l

F/M(COD) = 0.50 kg COD applied/day/kg MLSS

$F/M(TOC)_s$ = 0.070 kg soluble TOC applied/day/kg MLSS

$F/M(NH_3\text{-}N)$ = 0.028 kg NH_3-N applied/day/kg MLSS

F/M(TKN) = 0.43 kg NH_3-N applied/day/kg MLSS

Sludge Age = 10.4 days

Mixed Liquor D.O. Uptake Rate = 25.1 mg-hr/l

Return Sludge D.O. Uptake Rate = 34.3 mg-hr/l

Aeration Basin Temp = 24.2°C

Aeration Basin D.O. = 3.3 mg/l

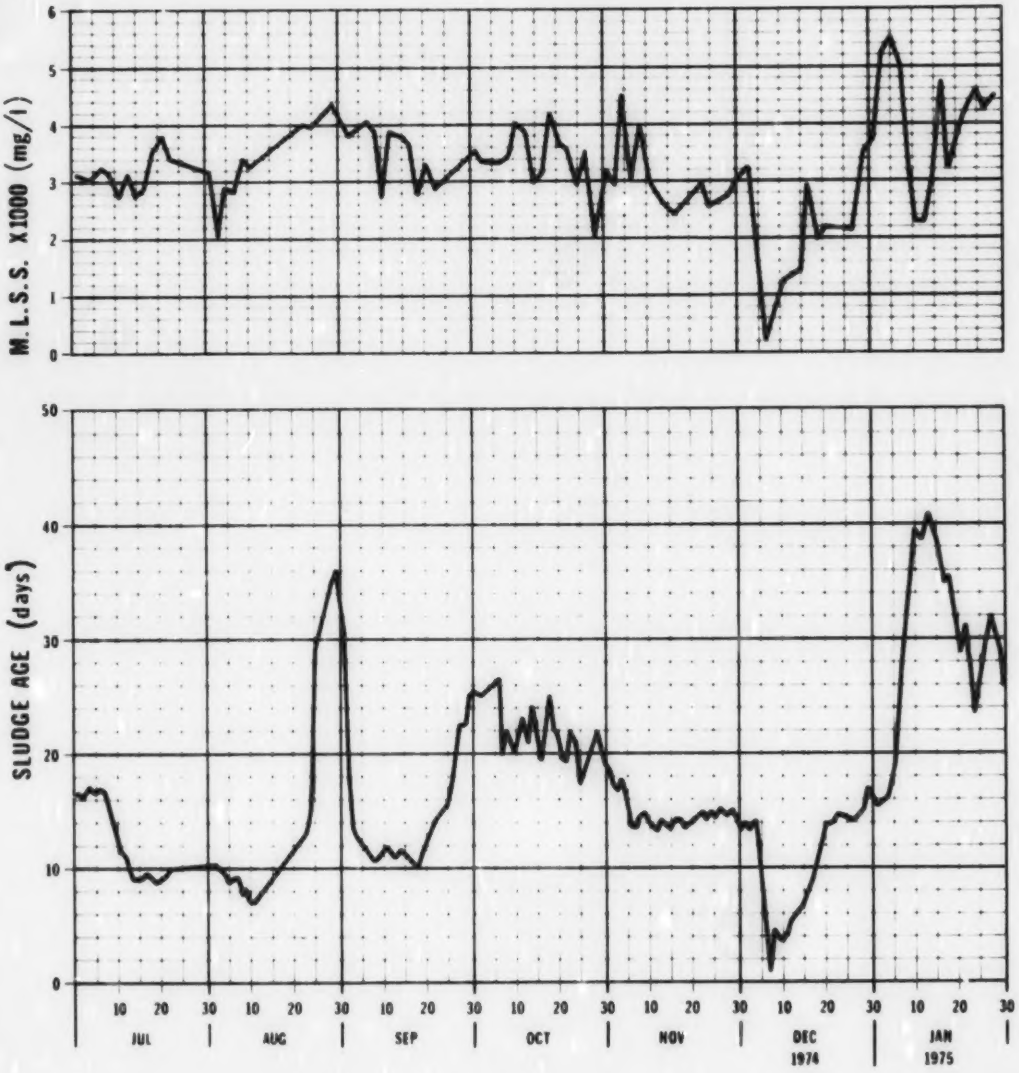

Figure 11. Mixed Liquor Suspended Solids concentrations and seven-day, moving-average sludge ages for the activated sludge process.

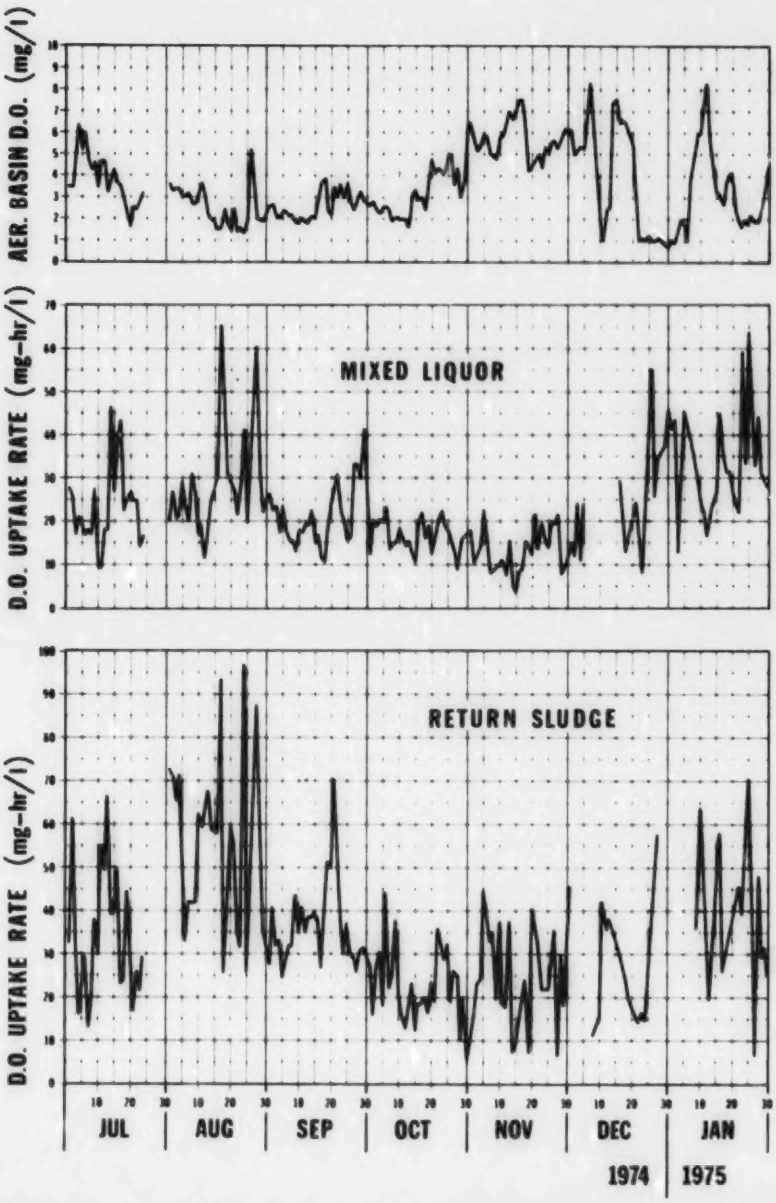

Figure 12. Aeration basin D.O. concentration and uptake for the completely-mixed activated sludge system.

an average of one day's operation. The return sludge uptake rates are higher than those for the mixed liquor, but obvious correlation exists.

Sludge volume index (SVI) values for the mixed liquor are shown in Figure 13. The activated sludge system at the Demonstaration Plant has always operated with SVI values that are higher than one would like; however, no adverse operation can be attributed to the high SVI. No attempt was made to relate SVI and sludge age or any other parameter since ferric chloride was fed to the aeration basin for three weeks.

Effluent ammonia nitrogen and total suspended solids concentrations for the project period are shown in Figure 14. Nitrification was generally good until December 7, 1974, at which time the previously discussed process upset resulted in a total loss of the nitrifying population. From mid-August to mid-October, 1974 nitrification was erratic. Sludge ages were consistently above ten days, and should have been adequate to support complete nitrification. During this two-month interval two maintenance problems were experienced at the Demonstration Plant, both of which had adverse effects on maintaining proper process control for a nitrifying biological system. First, one of the two air compressors in the oxygen transfer systems had bearing and overheating problems which resulted in the process becoming oxygen limited on occasion. Second, the influent magnetic flow meter on the activated sludge system was in almost constant need of calibration, making accurate flow measurement totally impossible.

Many of the peaks in effluent TSS shown in Figure 14 can be directly related to hydraulic washout from the secondary clarifier when influent flows increased, but were not indicated by the flow recorder.

Over the past several decades different investigators have reported problems with "rising sludge" in the secondary clarifiers of nitrifying activated sludge processes. The cause of the rising sludge has generally been attributed to uncontrolled denitrification in the secondary clarifier. Furthermore, uncontrolled denitrification appears to be prevalent when only partial nitrification is occurring. The experience gained at the Demonstration Plant tends to support the above observations; however, quantification of the findings has been difficult. Figure 15 presents effluent total suspended solids plotted as a function of effluent ammonia nitrogen. Some degree of correlation is obvious, but too many other variables are involved to permit definitive data analysis.

Effluent soluble TOC and effluent total COD concentrations for the activated sludge process are shown in Figure 16. The effluent soluble TOC data illustrate the capability of completely-mixed systems for removing soluble organic compounds. The major process upset of December 7, 1974 did little to increase the soluble TOC in the effluent. The observed transients in effluent COD concentrations are much more pronounced, as would be expected.

Figure 17 shows effluent COD as a function of effluent TSS. Considerable scatter exists; however, the indicated correlation is obvious. One can approximate a soluble COD of about 15 mg/l from this graph, and after coagulation and filtration the COD of the activated sludge effluent averaged

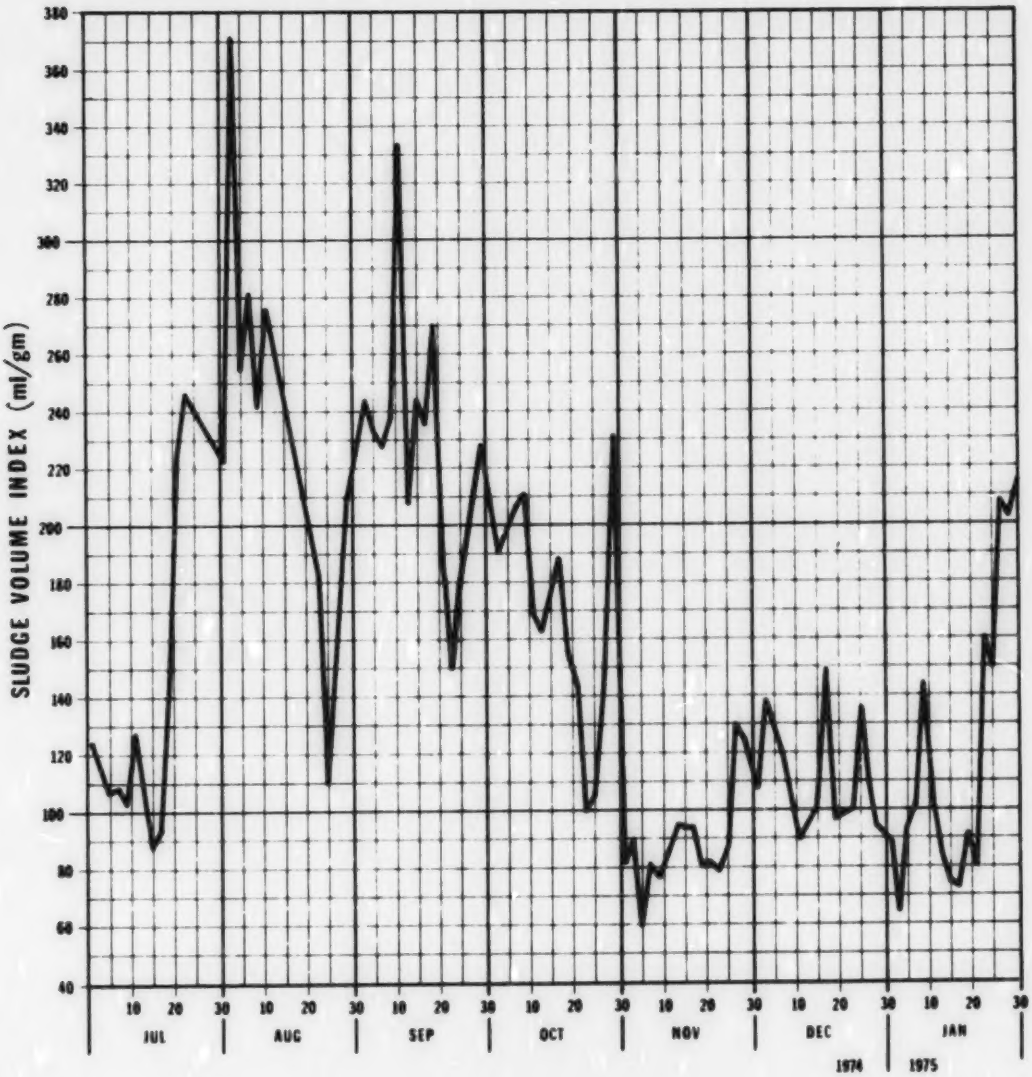

Figure 13. Sludge Volume Index for the activated sludge process.

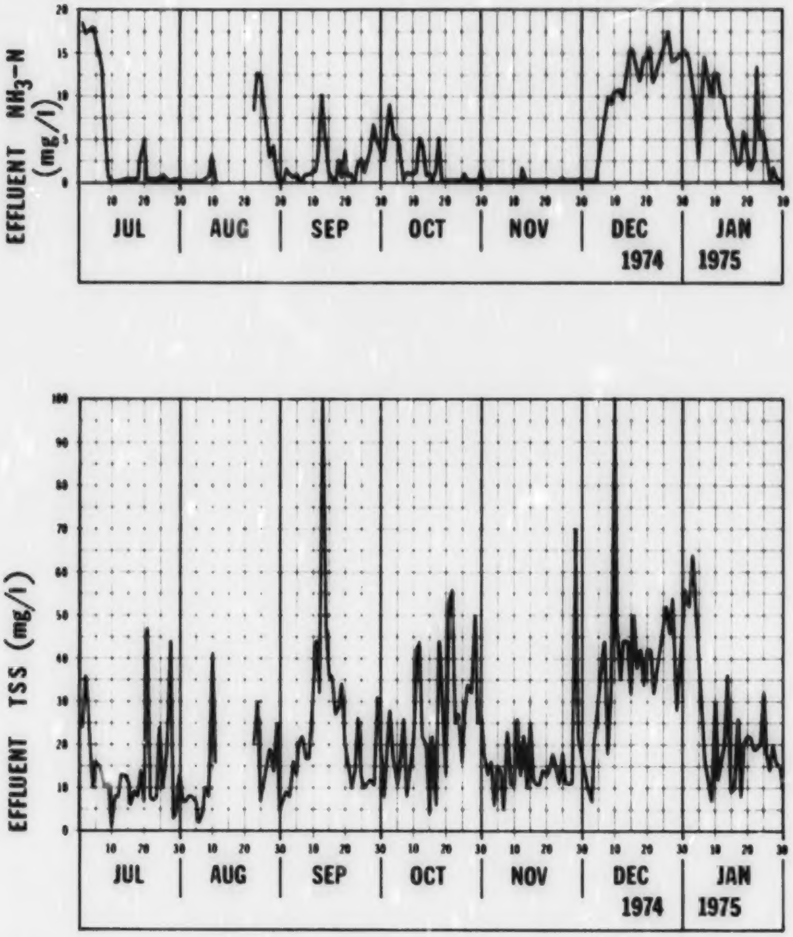

Figure 14. Effluent TSS and NH_3-N concentrations for the completely mixed activated sludge system.

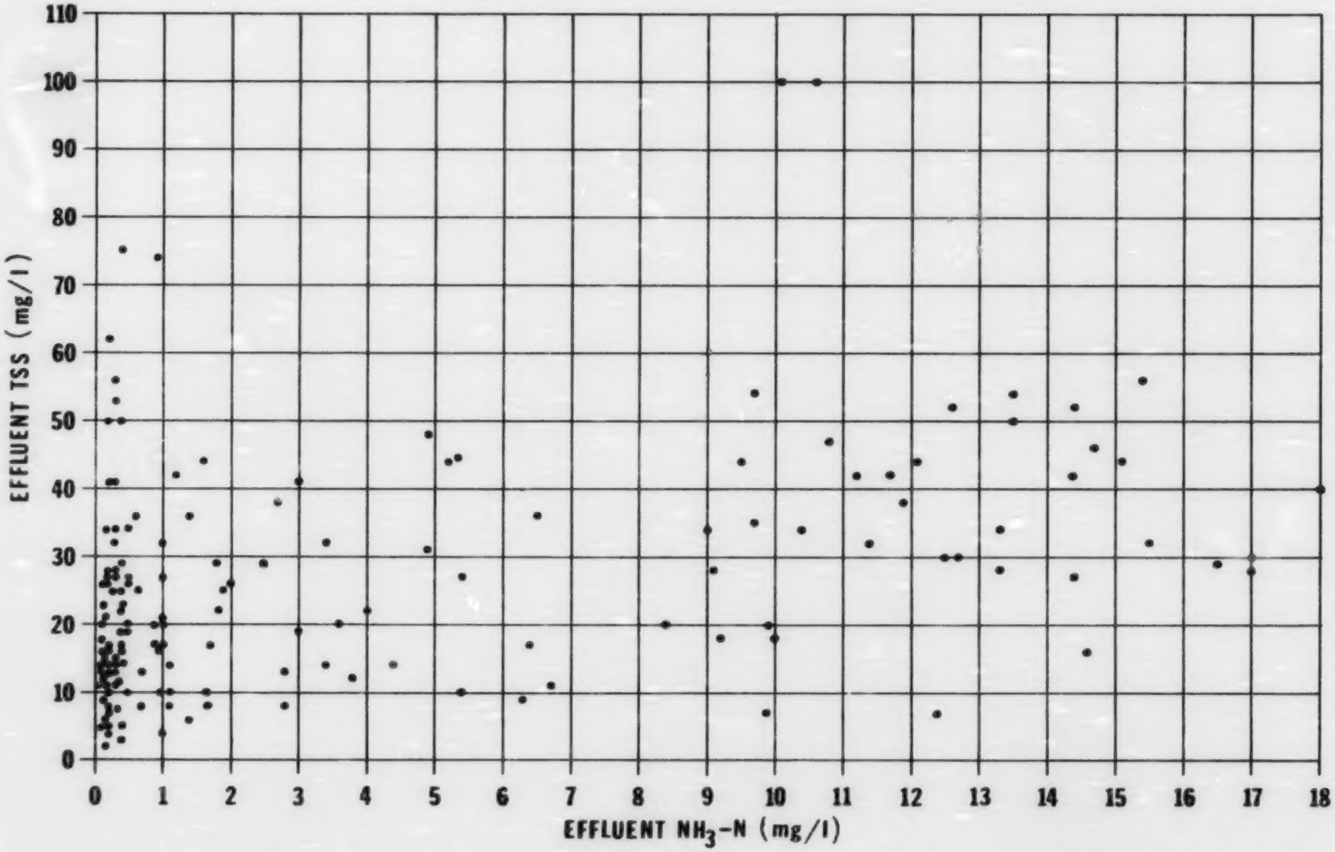

Figure 15. Effluent TSS as a function of effluent NH3-N for the activated sludge system.

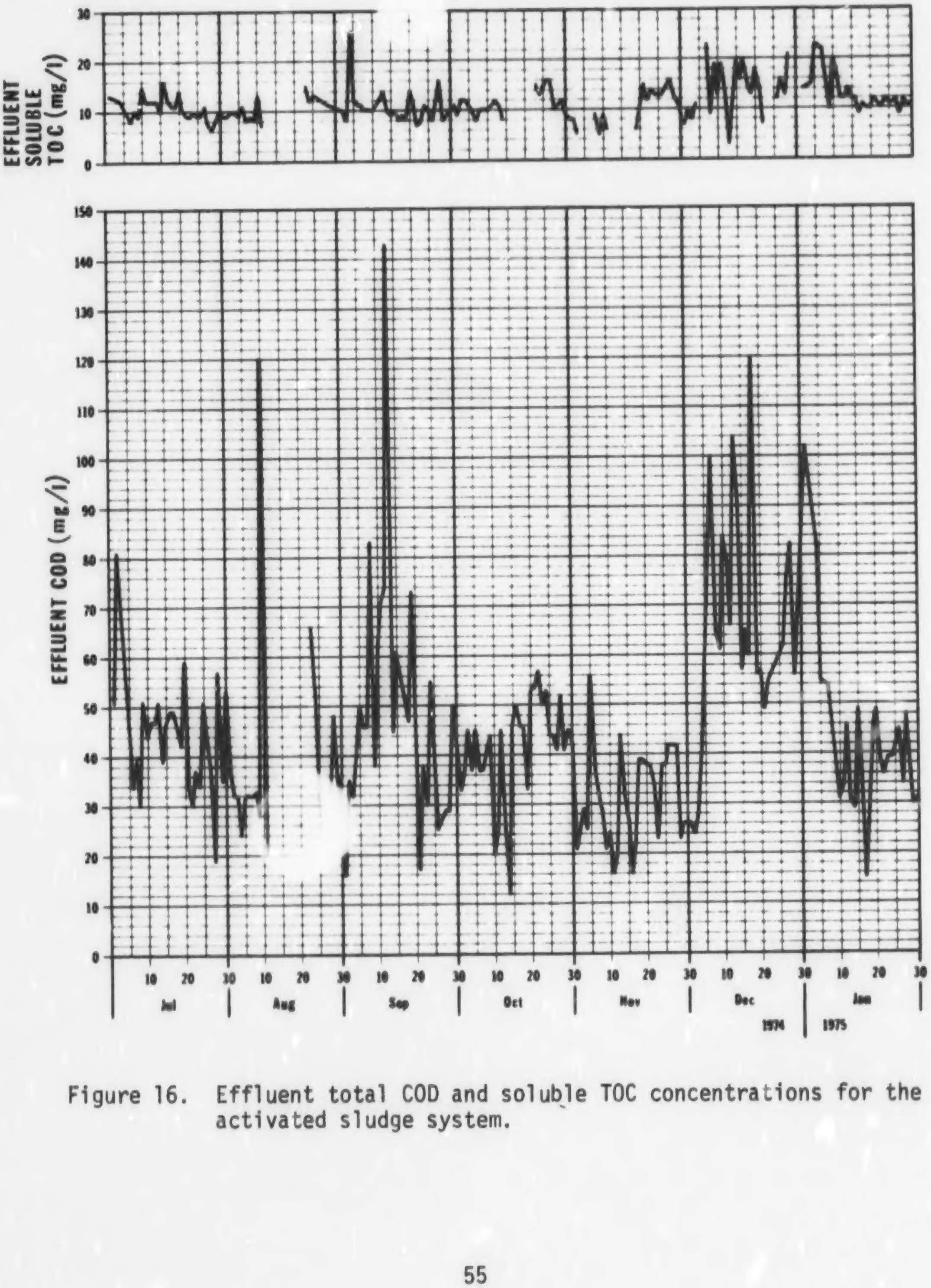

Figure 16. Effluent total COD and soluble TOC concentrations for the activated sludge system.

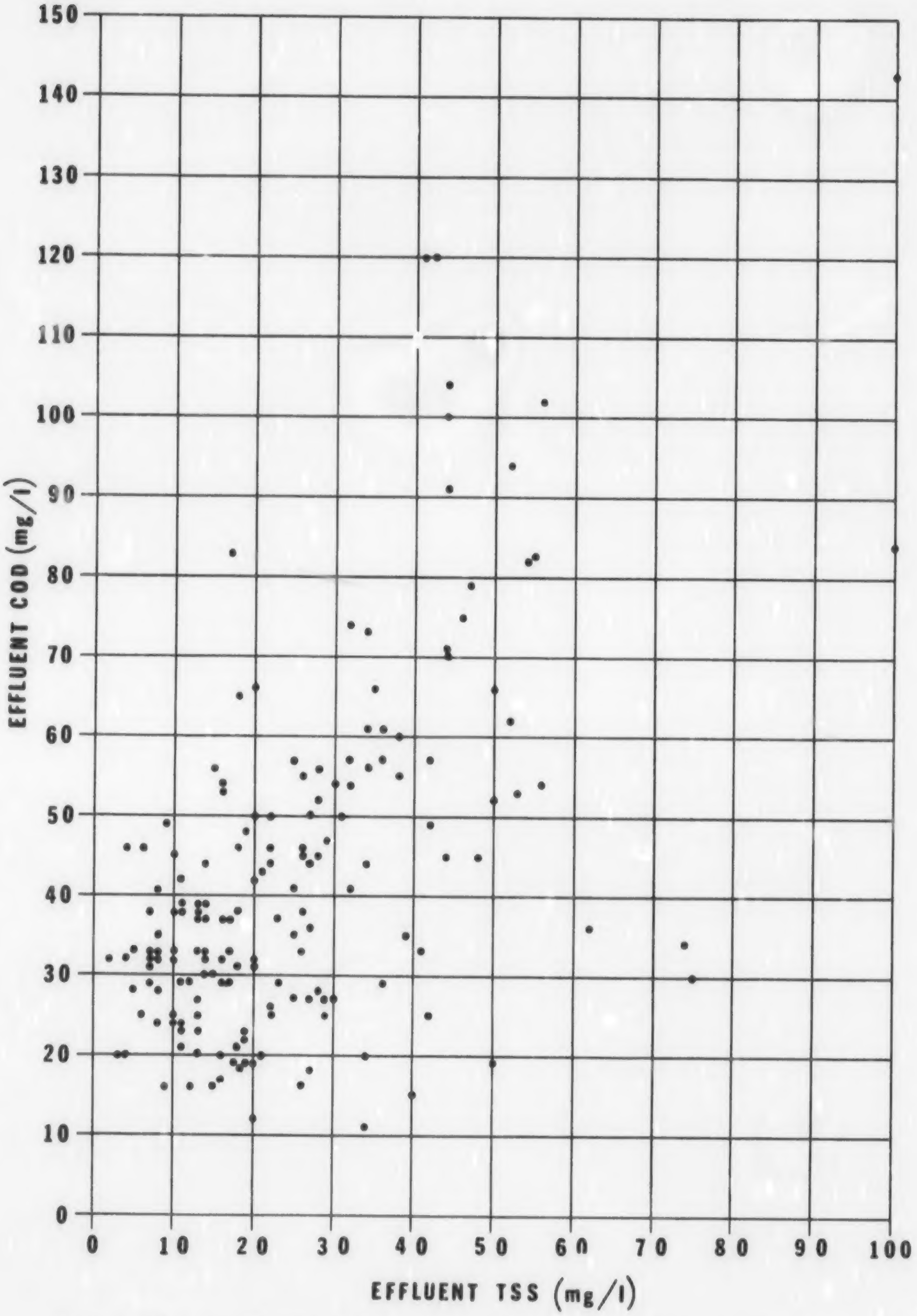

Figure 17. Effluent COD as a function of effluent TSS for the activated sludge system.

17 mg/l.

Between July and November 1974, the effluent COD concentration was typically 50 mg/l or less. On those days when the effluent COD was significantly higher, the effluent TSS were generally above 40 mg/l as a result of hydraulic overloading of the final clarifier.

Fecal coliform data for the activated sludge effluent are shown in Figure 18.

UPFLOW CLARIFIER

The upflow clarifier (Infilco Densator) at the Demonstration Plant was used as a high-pH lime coagulation, flocculation, and settling basin for the activated sludge effluent during this project. Hydrated lime was fed as the primary coagulant, and ferric chloride was fed as a flocculation aid during the first five months of the project. The average flow treated by the upflow clarifier was 6.88 liters per second (109 gpm), and the average hydrated lime dose was 284 mg/l.

The water quality data for the upflow clarifier are summarized in Table 15. During this project the total suspended solids in the upflow clarifier effluent were higher than expected. Figure 19 is a time-series plot of the effluent TSS, and also indicates monthly average ferric chloride doses (as $FeCl_3$). During the first four months of the study the average ferric chloride dose was 16 mg/l and the effluent TSS averaged about 30 mg/l. In an effort to reduce operating costs the average ferric chloride dose was reduced to 5.3 mg/l in November, and the increase in effluent TSS that resulted can be clearly seen in Figure 19. During December 1974 and January 1975, the ferric chloride feed was diverted to the activated sludge system, and the effluent TSS reflect this change in operation.

Another factor which was contributory to the high TSS was the absence of sludge recirculation. The Densator has the capability of solids contact operation when utilizing lime as the primary coagulant. However, the sludge recirculation pump was used to pump the upflow clarifier effluent to the recarbonation basin, and not for sludge recirculation needed for solids contact operation. Prior experience with solids contact operation indicates that the sludge recirculation is effective in reducing effluent solids carry over and effluent turbidity.

A fifty percent reduction in COD was observed and can be directly attributed to the removal of volatile suspended solids from the activated sludge effluent. Although the effluent TSS from the upflow clarifier were high, the volatile suspended solids rarely exceeded 5 mg/l.

The only significant change in the nitrogen forms was the 1.2 mg/l decrease in organic nitrogen that resulted from the removal of volatile suspended solids. The effluent suspended solids from an activated sludge process are about eight percent nitrogen by weight, therefore, the 1.2 mg/l organic nitrogen decrease is approximately equal to a 15 mg/l decrease in

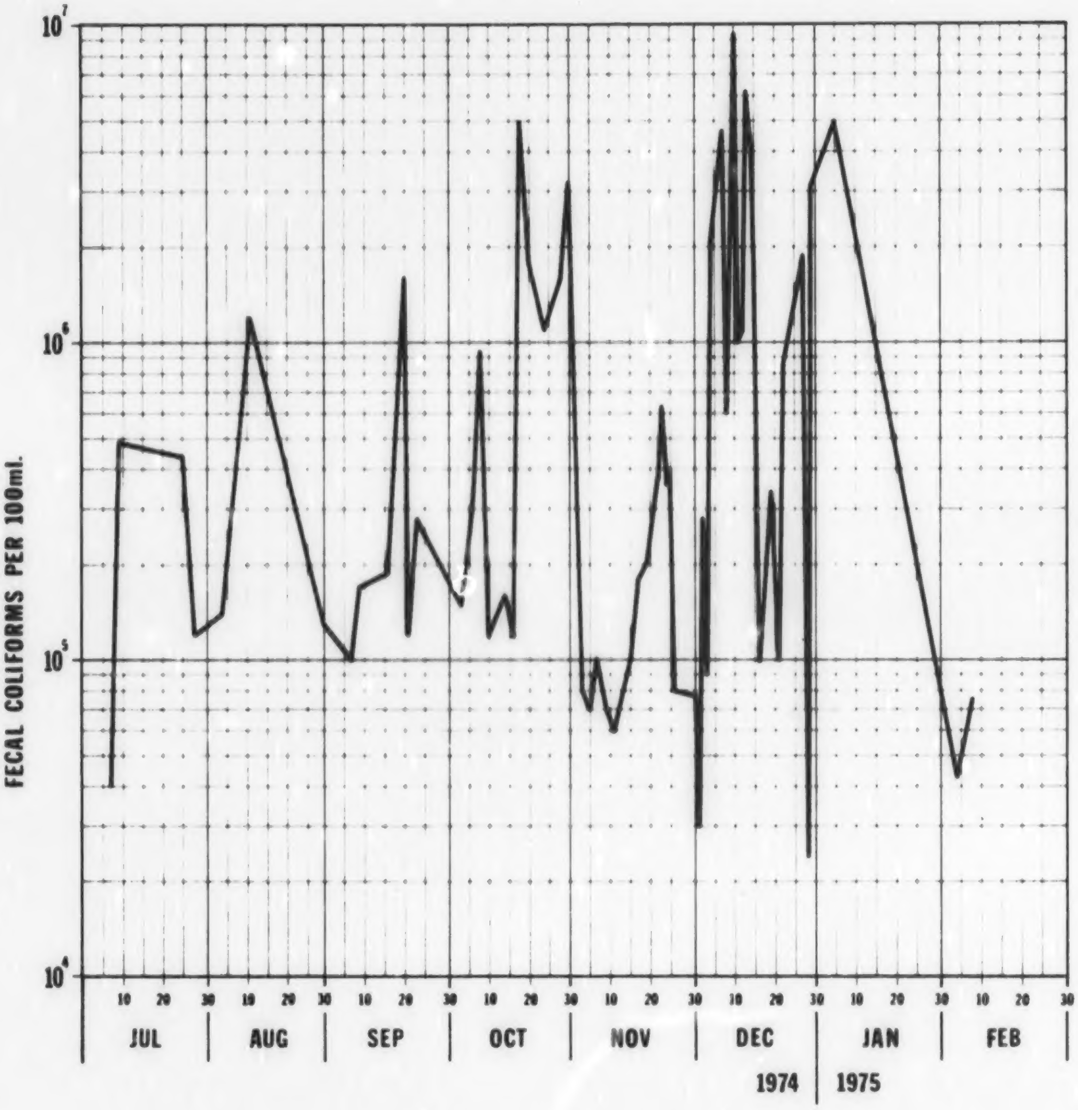

Figure 18. Fecal coliform for the activated sludge effluent.

TABLE 15

WATER QUALITY SUMMARY FOR THE UPFLOW CLARIFIER

Parameter	Activated Sludge Effluent (mg/l)	Upflow Clarifier Effluent (mg/l)	Reduction (percent)
TSS	22	72	--
COD	44	22	50.0
Soluble TOC	11.3	8.8	22.1
NH_3-N	3.7	2.8	24.3
Org.N	3.2	2.0	37.5
TKN	6.9	4.8	30.4
NO_2&NO_3-N	6.5	6.7	30.4
NO_2-N	0.55	0.74	--
Total N	13.4	11.5	14.2
Total P	6.0	1.02	83.0
pH	7.3	10.95	83.0
TPC/ml	2.1×10^5	$<4.7\times10^1$	>99.98
Total Coli/100ml	9.1×10^5	<3.7	>99.9996
Fecal Coli/100ml	1.3×10^5	<3.2	>99.997

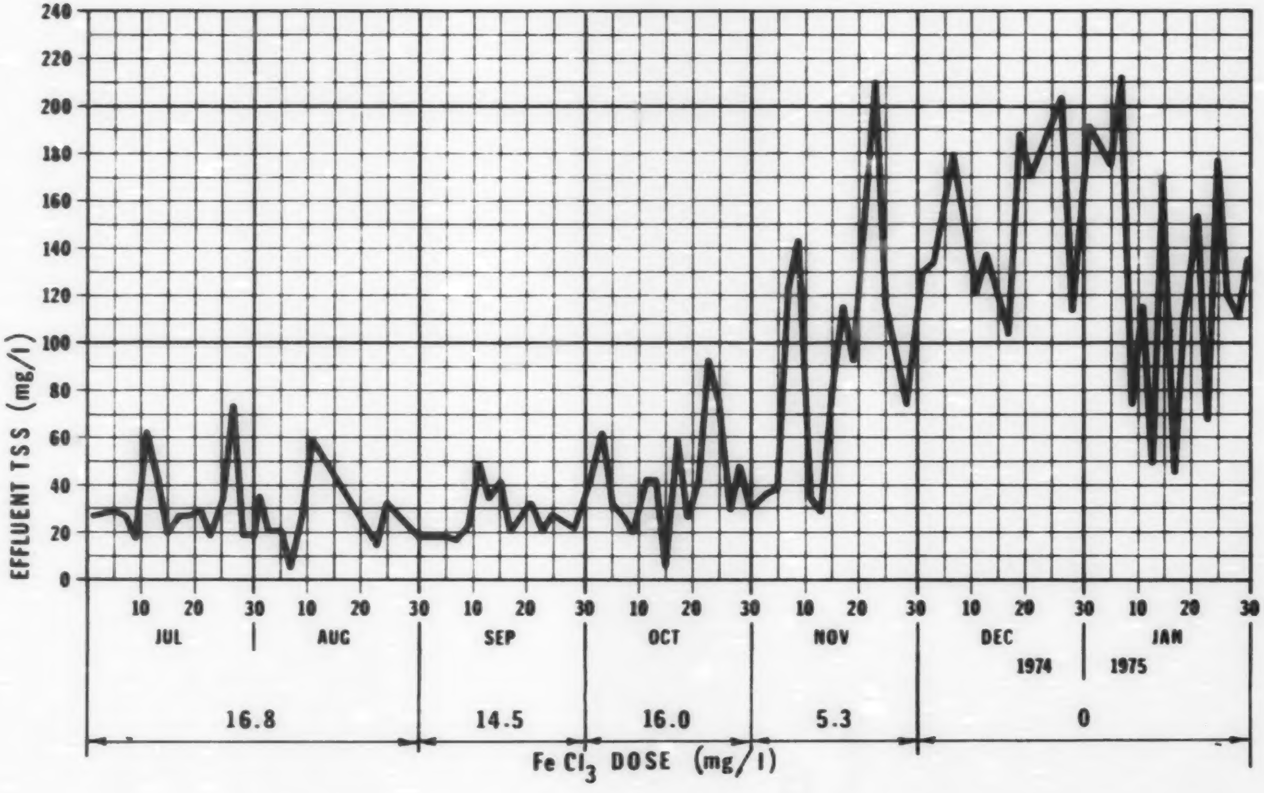

Figure 19. Upflow clarifier effluent TSS and ferric chloride doses.

the suspended solids present in the activated sludge effluent.

The reduction in total phosphorus (83 percent) was good, but not excellent. Figure 20 presents the total phosphorus concentrations in the effluent of the upflow clarifier during this study, and a strong correlation with effluent TSS is evident. The pH in the upflow clarifier and the total phosphorus concentrations in the effluent from the mixed-media filter are shown in Figure 21. These data behave as expected, and predict a total phosphorus concentration of less than 0.5 mg/l when the pH is above 11.0.

The control of pH proved to be a more difficult problem than initially anticipated. Figure 22 presents the pH values observed in the effluent of the upflow clarifier. The principal process control criterion for the upflow clarifier was to maintain a pH of 11.3. Clearly this condition was seldom satisfied. Lime feed was difficult to control due to several factors, the most serious of which was the line carrying the lime slurry to the upflow clarifier. The line is a 1.9 cm (3/4 inch) PVC pipe about 15 meters (50 feet) in length, and scale build-up is quite rapid. Approximately 11 liters of 1:1 HCl were pumped through the lime feed line once a week to control scale, and this procedure was relatively successful in preventing blockages. Additionally the calcium hydroxide content of the commercial lime varied from a high of 98 percent to a low of 60 percent, which necessitated changes in lime feed rates with each load of lime.

Although the pH in the upflow clarifier was slightly lower than the intended value of 11.3, excellent bacterial kills were observed in this unit process. Total plate counts were reduced almost four logs to a geometric mean of less than 47 per ml for the project period. Greater than four log reductions were observed for both total and fecal coliforms. The geometric mean for total coliforms was less than 3.7 per 100 ml, and less than 3.2 per 100 ml for fecal coliforms.

Effluent total plate count and fecal coliform data for the upflow clarifier effluent are shown in Figure 23. The total count data have been converted to an organisms per 100 ml basis, such that the values are consistent with the fecal coliform data. Positive tubes were found on only seven of the forty-nine samples set up for fecal coliform determinations. The total plate counts exhibited considerable variability, and were about three logs higher than the fecal coliform data.

SINGLE STAGE RECARBONATION BASIN

A galvanized steel tank, 1.83 meters (6 feet) in diameter and 3.66 meters (12 feet) in depth, was used as the single-stage recarbonation basin during this study. The basin had an effective liquid depth of 3.40 meters (11 feet-2 inches). Effluent from the upflow clarifier was pumped through a 5.08 cm (2 in.) PVC line, and entered the recarbonation basin 36 cm (14 in.) above the tank bottom. The effluent from the recarbonation basin flowed over a 90° V-notch weir and into a trough piped to the suction-side of a centrifugal pump.

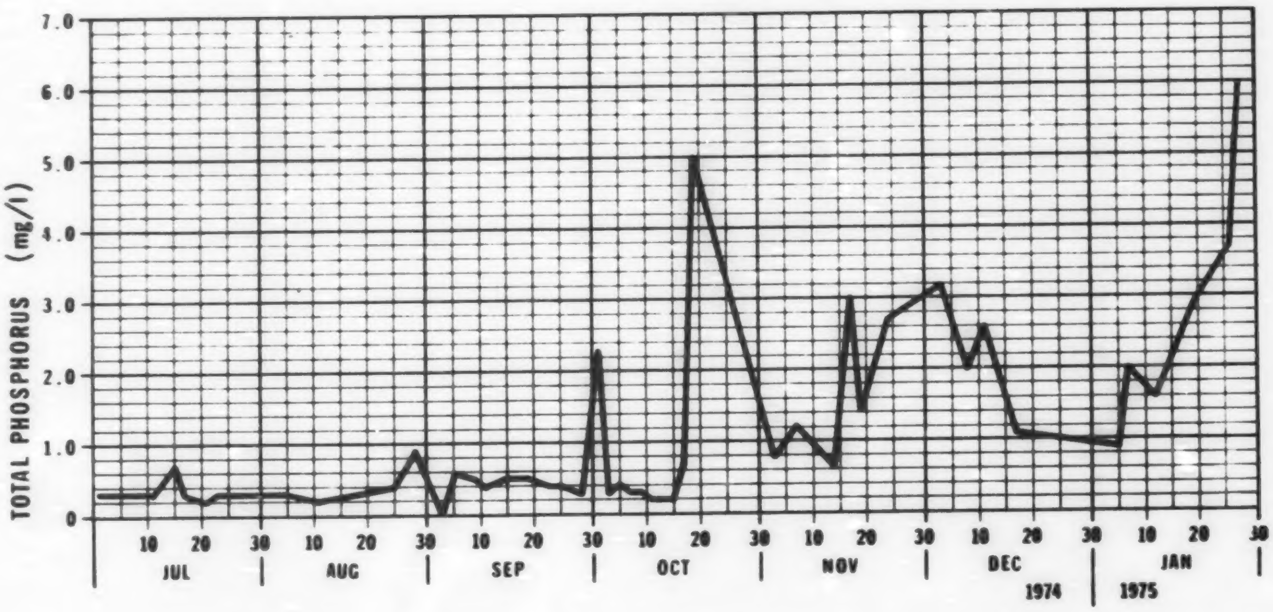

Figure 20. Total phosphorus concentrations observed in the upflow clarifier effluent.

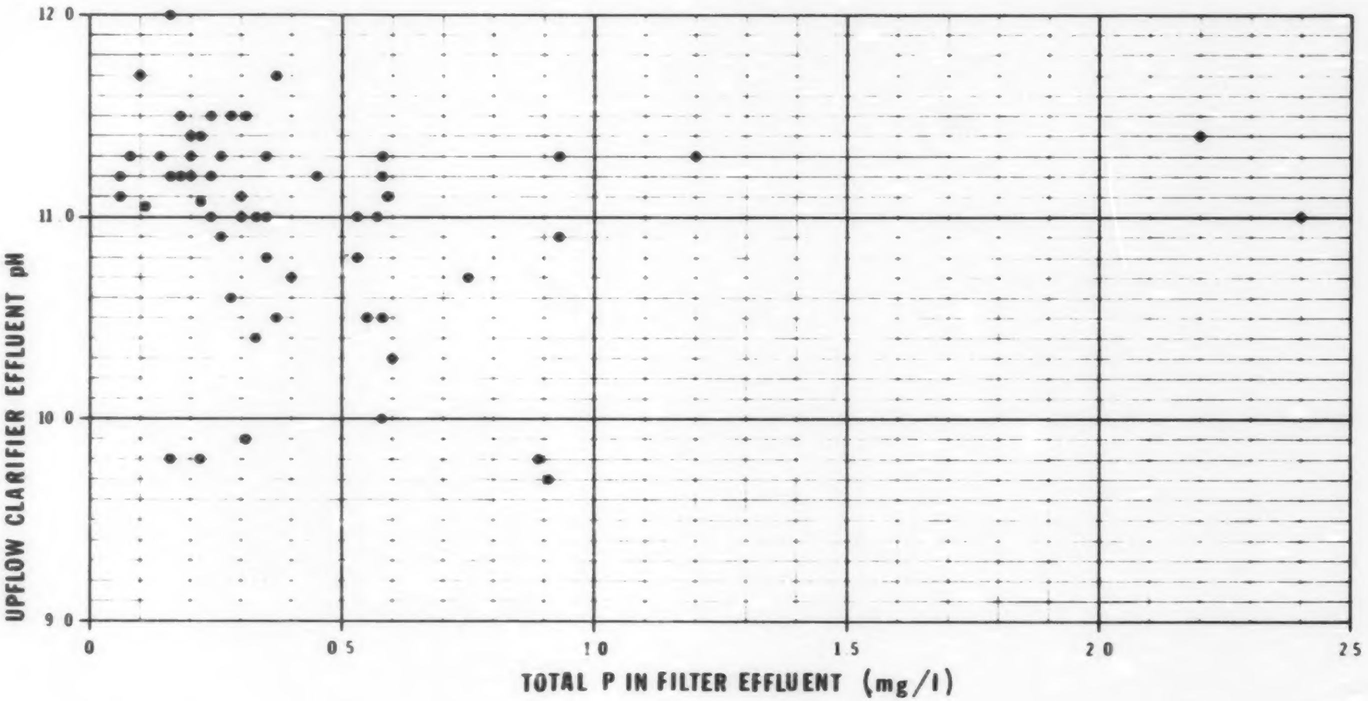

Figure 21. Total phosphorus as a function of pH.

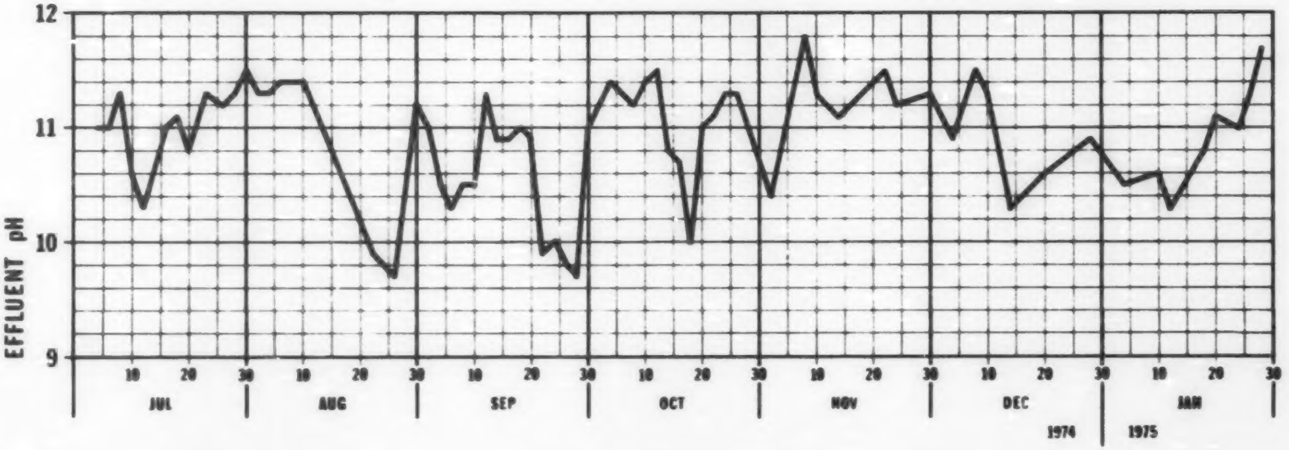

Figure 22. Upflow clarifier effluent pH values.

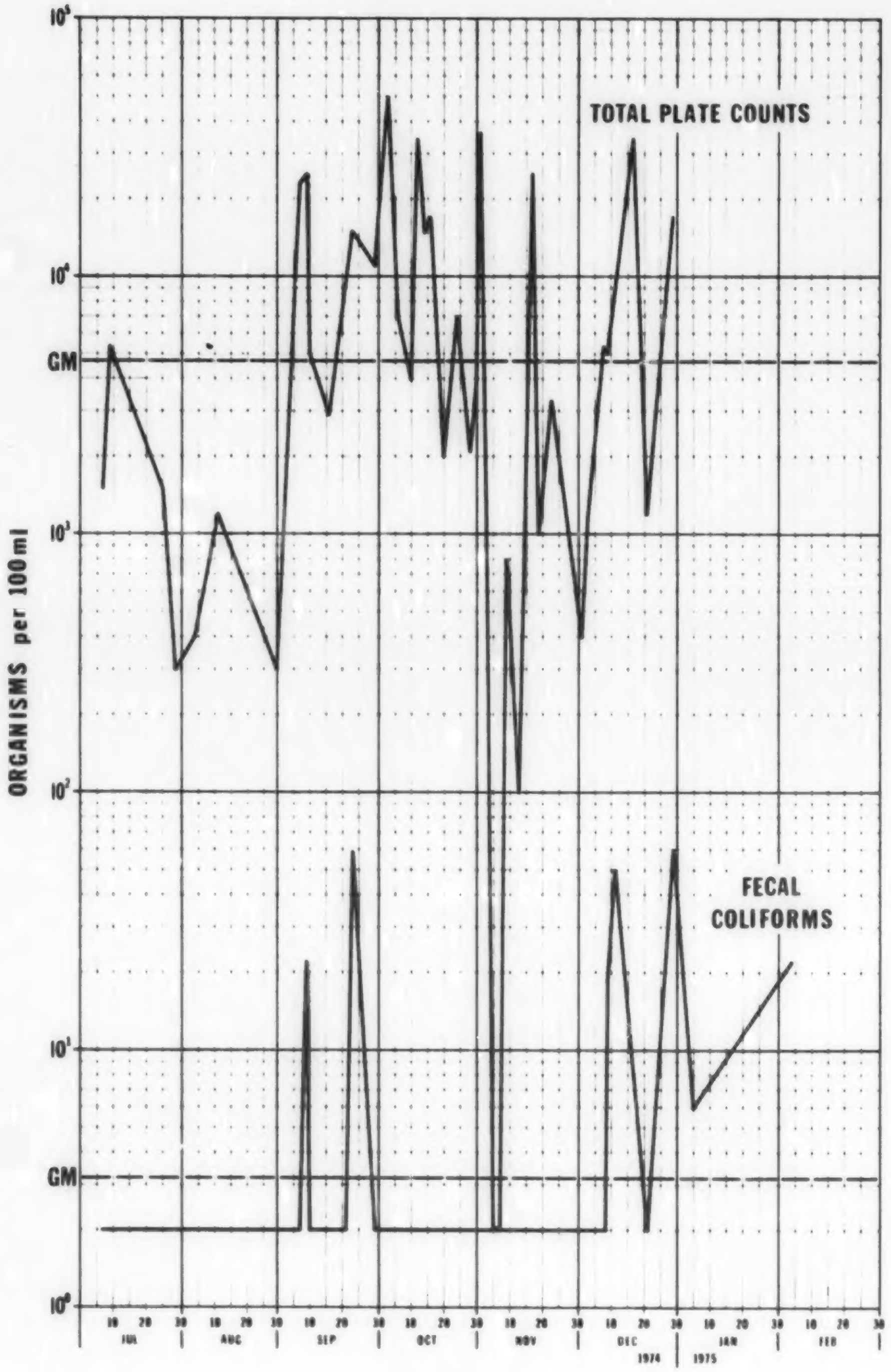

Figure 23. Effluent total plate counts and fecal coliforms for the upflow clarifier.

Liquid carbon dioxide was stored in a 5.4×10^4 kg (6 ton) receiver. The liquid carbon dioxide was passed through a pressure regulator and flow meter, and into the 1.27 cm (1/2 in.) PVC diffusers mounted 0.3 meters (1 foot) above the bottom of the recarbonation basin. The average carbon dioxide dose for this project period was 420 mg/l (3489 lbs./10^6gal.).

Water quality data for the recarbonation basin are summarized in Table 16. As utilized in this study, recarbonation is principally a pH control process and the water quality data indicate few significant changes, except for pH, which was reduced from a mean value of 10.95 to 6.9.

Effluent pH values for the recarbonated effluent are shown in Figure 24. The pH value desired during the study was 7.0, and these data indicate the pH generally ranged from 6.5 to 7.0. The lime-coagulated activated sludge effluent had very low buffering capacity at neutral pH values, and the plant operators found it possible to maintain better process control at slightly lower pH values.

The recarbonation basin was operated at an average flow of 3.8 liters/sec. (61 gpm), which resulted in a theoretical residence time of 39 minutes. Under these conditions the basin had a surface overflow rate of 126.4m^3m^2/day (3104 gpd/sq.ft.), which is sufficiently low to permit some settling. Total suspended solids removal averaged 59.7 percent, and the effluent TSS concentration averaged 29 mg/l. The fifty percent reduction in total phosphorus is in excellent agreement with the TSS removal, and should be expected.

NO. 1 MIXED-MEDIA FILTER

The No. 1 mixed-media filter is a relatively conventional gravity filter equipped with Neptune Microfloc media (anthracite, sand, and garnet). During this research effort, this filter was used to process the activated sludge effluent that had been chemically coagulated with lime and recarbonated. The water quality data for this unit process are summarized in Table 17. The only water quality parameters that were significantly affected by filtration were total suspended solids, turbidity, and COD.

A 29.2 percent decrease in COD was observed across the filter, and this reduction can be attributed to the removal of volatile suspended material from the product water. The arithmetic mean of the effluent COD values was 17 mg/l, which indicates that good treatment usually preceded filtration. Figure 25 is a time-series plot of the effluent COD concentrations observed for the filter, and for practical purposes these values are indicative of the soluble COD in the activated sludge effluent. During the months of July and August 1974, the COD values averaged approximately 20 mg/l and a constant decrease occurred in COD concentration until early December 1974, when the average value was 9 mg/l. The major process upset of early December is clearly evident, since the mean COD concentration increased over 300 percent. It is interesting to note that with only 400 mg/l of MLSS in the aeration basin the COD in the filter effluent never exceeded 35 mg/l. A gradual decrease in the COD concentration in the filter effluent occurred as the microbial population in the aeration basin increased, and at the termination

TABLE 16

WATER QUALITY SUMMARY FOR THE SINGLE-STAGE RECARBONATION BASIN

Parameter	Upflow Clarifier Effluent mg/l	Recarbonation Basin Effluent mg/l	Reduction (percent)
TSS	72	29	59.7
COD	22	24	--
Soluble TOC	8.8	11.1	--
NH_3-N	2.8	3.5	--
Org. N	2.0	1.9	5.0
TKN	4.8	5.4	--
NO_2&NO_3-N	6.7	6.1	9.0
NO_2-N	0.74	0.55	25.7
Total N	11.5	11.5	--
Total P	1.02	0.51	--
pH	10.95	6.9	50.0
TPC/ml	$<4.7\times10^1$	3.7×10^4	--
Total Coli/100ml	<3.7	750	--
Fecal Coli/100ml	<3.2	44	--

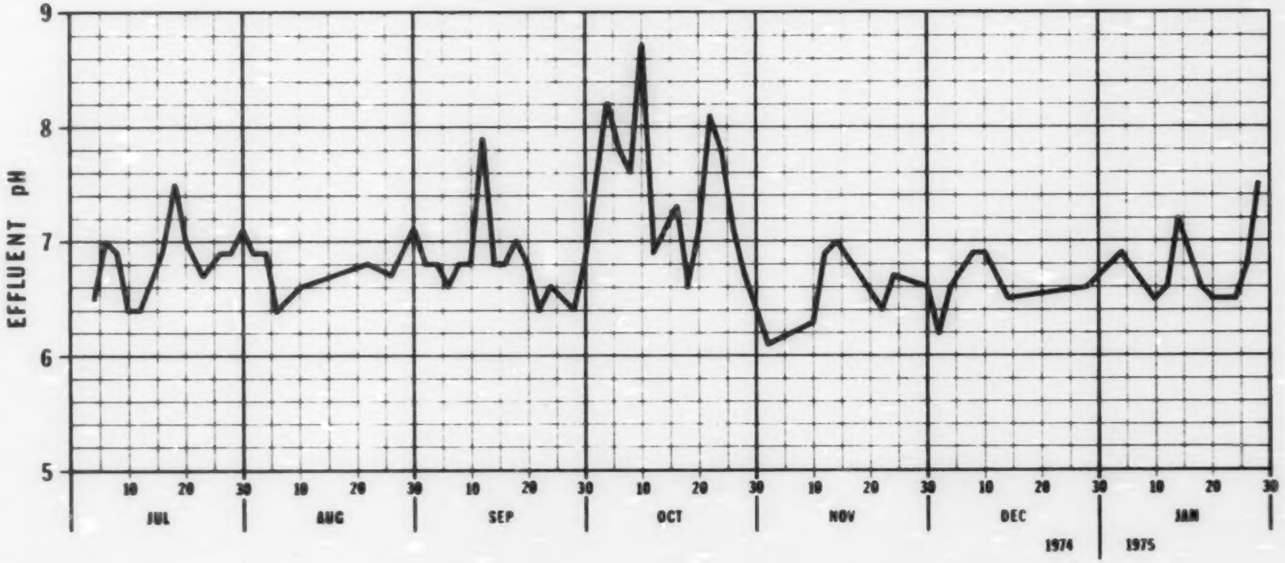

Figure 24. Effluent pH values for the single-stage recarbonation basin.

TABLE 17

WATER QUALITY SUMMARY FOR THE NO. 1 MIXED-MEDIA FILTER

PARAMETER	RECARBONATION BASIN EFFLUENT (mg/1)	NO. 1 MIXED-MEDIA FILTER EFFLUENT (mg/1)	REDUCTION (PERCENT)
TSS	29	17	41.4
COD	24	17	29.2
Soluble TOC	11.1	10.1	9.0
NH_3-N	3.5	3.3	5.7
Org. N.	1.9	1.8	5.3
TKN	5.4	5.1	5.6
NO_2 & NO_3-N	6.1	6.0	1.6
NO_2-N	0.55	0.52	5.4
Total N	11.5	11.1	3.5
Total P	0.51	0.45	11.8
pH	6.9	6.8	--
Color (Pt-Co)	--	11	--
Hardness	--	155	--
Turbidity (FTU)	--	4.8	--
F^-	--	1.15	--
SO_4	--	90	--
TPC/ml	3.7×10^4	8.7×10^3	76.5
TC/100 ml	7.5×10^2	1.5×10^3	--
FC/100 ml	4.4×10^1	4.3×10^2	--

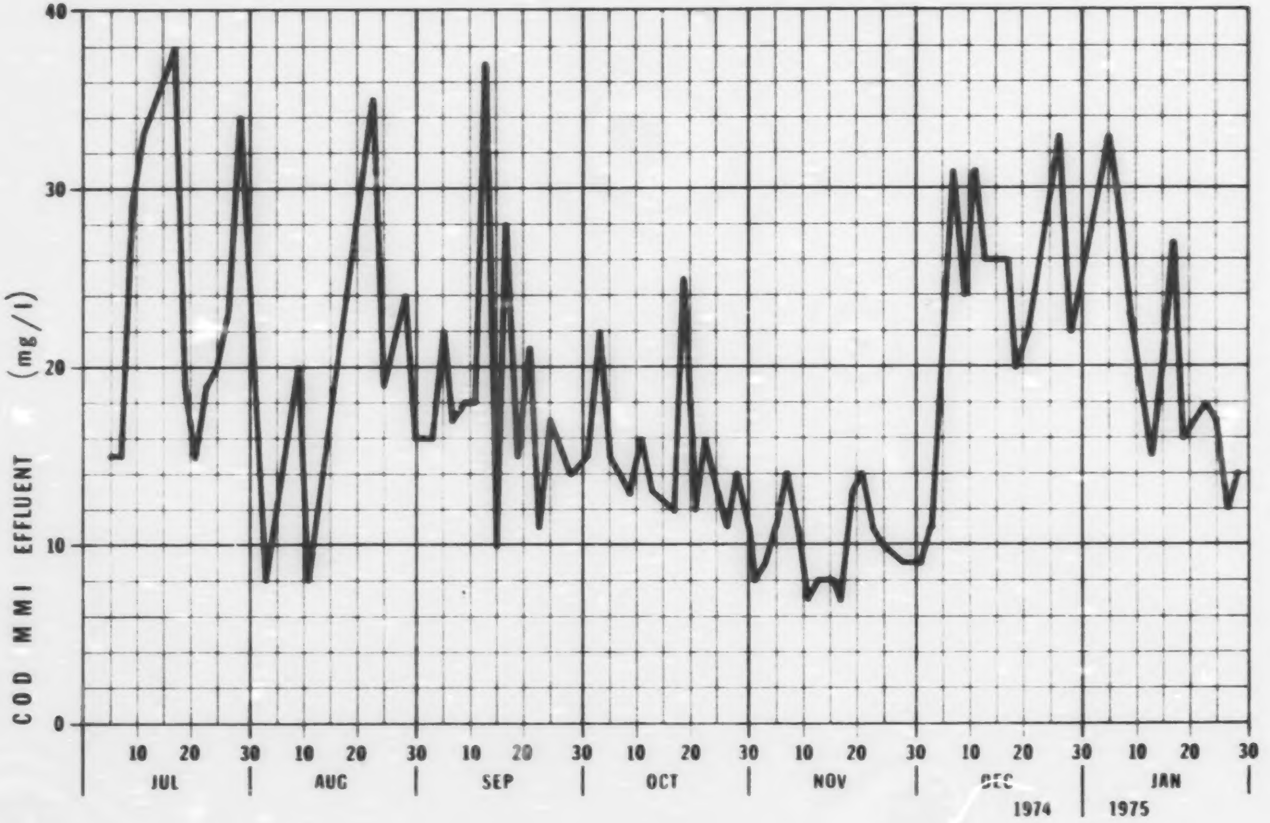

Figure 25. Effluent COD values for the mixed-media filter.

of the project the COD concentration in the filter effluent had returned to very low levels.

The average effluent values for both TSS and turbidity are much higher than one would expect for a filtered water. Figures 26 and 27 are plots of the effluent TSS concentrations and turbidity values, respectively. Quite obviously two major breakthroughs occurred, one in July the other in September 1974. With the exception of those two instances, effluent TSS and turbidity are good.

As directed by their supervisor, the plant operators were backwashing the filter at a rate of 8.9 liters/sec./meter^2 (13.2 gpm/ft.^{2}) until late September. During that time the filter was inadequately cleaned during the backwashing procedure, and the result was cracking of the filter-bed on two occasions. Figure 28 presents bed expansion data for the filter as a function of backwash rate. Under normal operating conditions the desired bed expansion would be in the range of 30 to 50 percent, and an expansion of only 12 percent is realized at a backwash rate of 8.9 liters/sec./m^2(13.2 gpm 1 ft.^{2}). After September 1974, the backwash rate was increased to 12.2 liters/sec./m^2 (18 gpm/ft.^{2}) and filter performance was substantially improved.

Sporadic turbidity breakthrough is evident after the backwash rate was increased, and this problem can be attributed to one major difficulty. The surface wash system on the filter was inadequate when the filter was modified for the Microfloc media. As a result of inadequate service water pressure and a poor bearing assembly, the surface wash worked only infrequently and this had an adverse effect on filter performance, and periodic turbidity breakthrough resulted.

Table 18 presents a month by month summary of the operation of the mixed-media filter, and a summary for the complete project period. When considered in terms of hours of service between backwash cycles, the filter operation was good, averaging 51 hours. The wash-water consumption represented only 2.85 percent of the total filtered product water, and the average filtration rate of 1.90 liters/sec/meter^2 (2.8 gpm/ft.^{2}) was selected to be representative of typical filter operations.

ACTIVATED CARBON CONTACTORS

The two granular activated carbon contactors at the Demonstration Plant were operated in series for this research project. Each contactor was loaded with 1700 kg (3750 lbs.) of Calgon Filtrasorb 400, with a mesh size of 12 x 40. The carbon beds were 1.22 meters (4.0 feet) in diameter and 3.05 meters (10.0 feet) deep. The carbon in the No. 4 Column had been previously used, but had been very lightly loaded, while the carbon in the No. 3 Column was virgin.

The No. 4 Column always preceded the No. 3 Column in the treatment sequence, and the contactors were operated at average flows of 1.9 liters per second (30.6 gpm) and 1.05 liters per second (16.7 gpm), respectively. The theoretical empty-bed contact time (EBCT) was 30.7 minutes for the No. 4

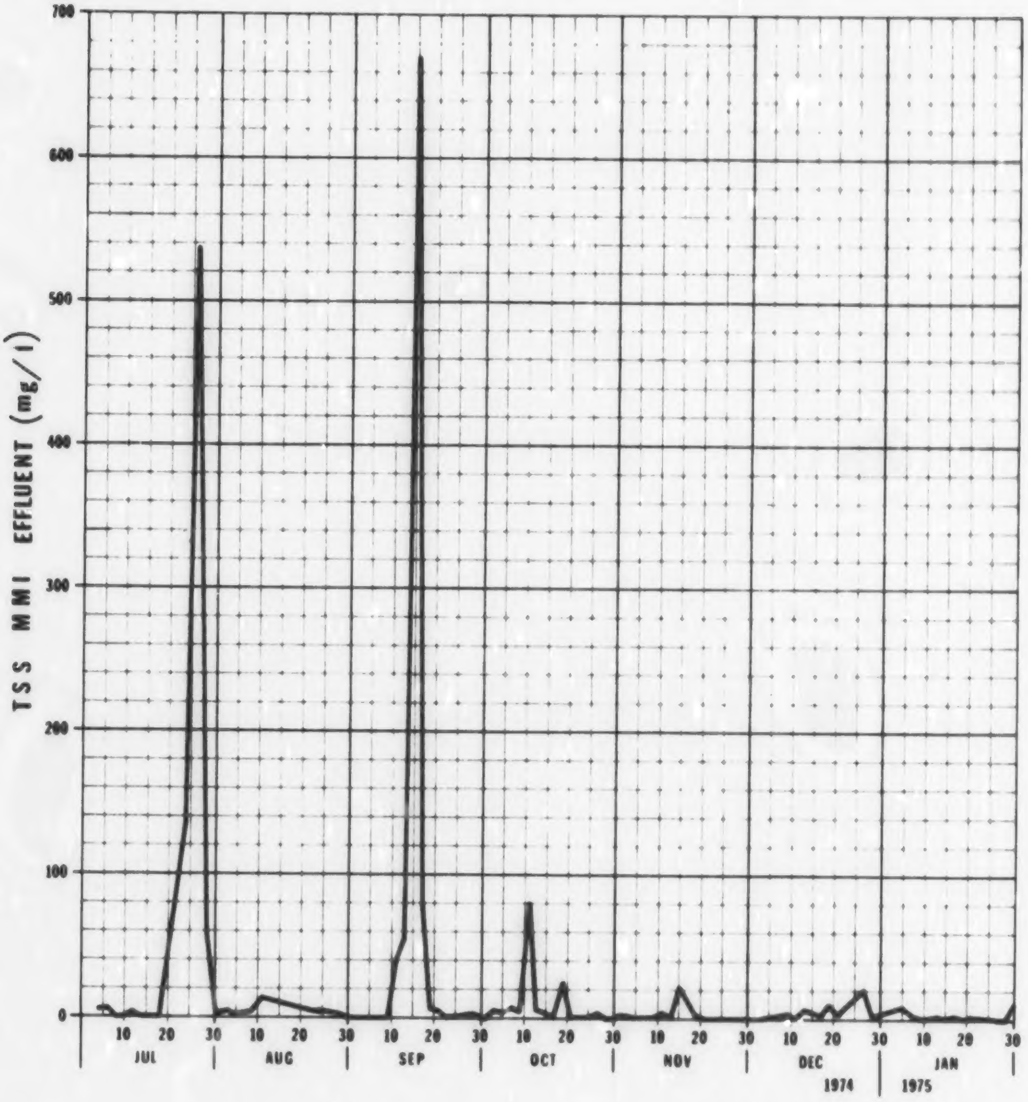

Figure 26. Effluent total suspended solids concentrations for the mixed-media filter.

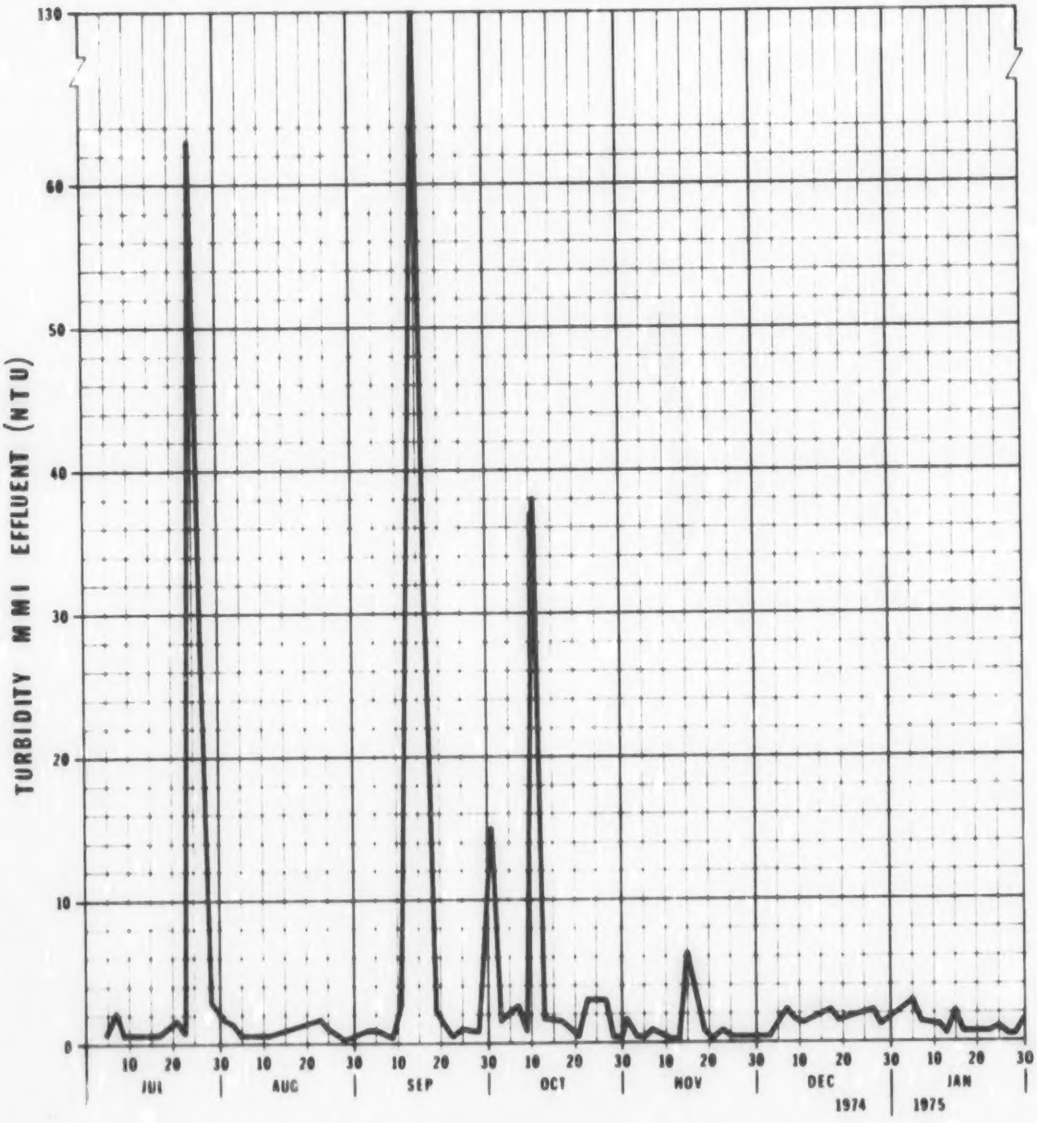

Figure 27. Effluent turbidity values for the mixed-media filter.

TABLE 18

OPERATIONS SUMMARY FOR THE NO. 1 MIXED-MEDIA FILTER

Month	Product Water (liters x 10^6) (gals. x 10^6)	Backwash Water (liters x 10^4) (gallon x 10^4)	Number of Washes	Avg. Hours Between Washes	Filtration Rate (liters/sec./m^2) (gpm/ft.^{2})	Washwater Used (percent of product)
July, 1974	3.872 (1.023)	6.47 1.71	10	53	1.76 (2.6)	1.7
Aug., 1974	3.077 (0.813)	4.542 (1.20)	6	72	1.70 (2.5)	1.5
Sept., 1974	6.143 (1.623)	13.32 (3.52)	15	48	2.04 (3.0)	2.2
Oct., 1974	6.658 (1.759)	37.32 (9.86)	24	31	2.17 (3.2)	5.6
Nov., 1974	6.082 (1.607)	16.18 (4.27)	13	55	2.04 (3.0)	2.7
Dec., 1974	4.868 (1.286)	14.19 (3.75)	12	56	1.76 (2.6)	2.9
Jan., 1975	5.443 (1.438)	10.83 (2.86)	10	74	1.76 (2.6)	2.0
Total for Project	36.143 (9.549)	102.88 (27.18)	90	51	1.90 (2.8)	2.85

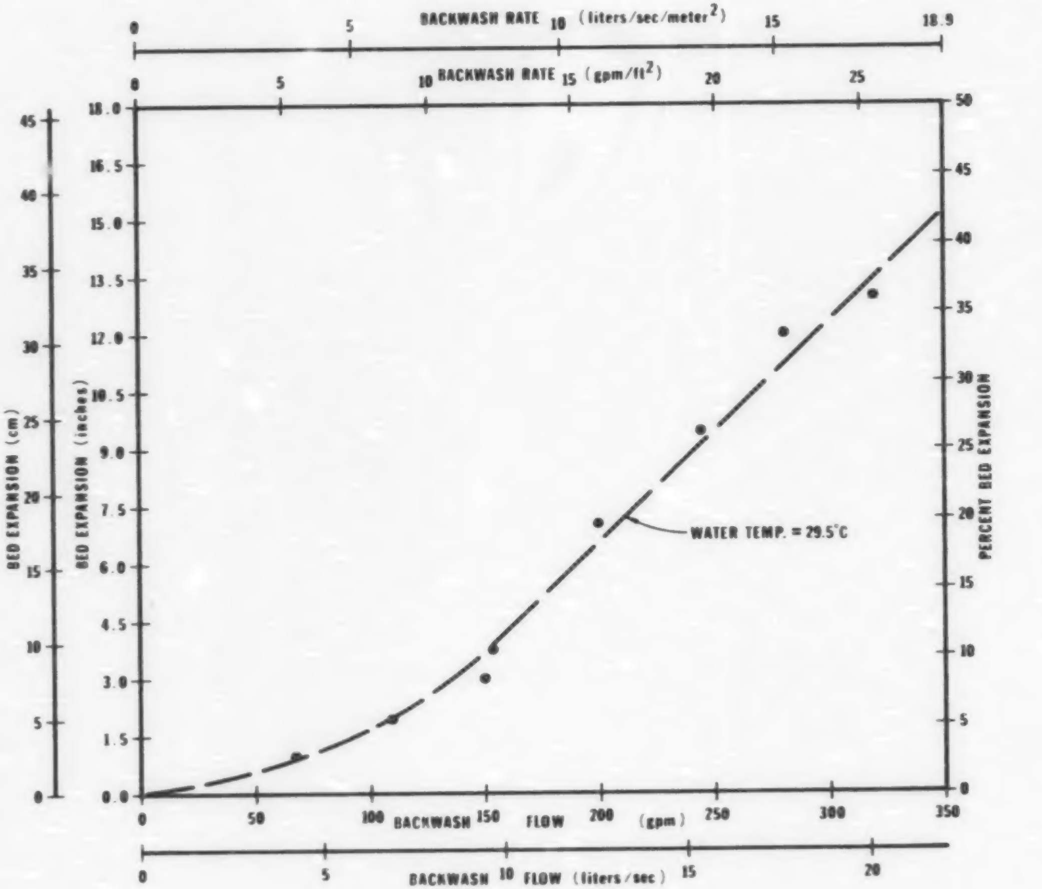

Figure 23. Media expansion characteristics for the No. 1 mixed-media filter.

Column and 56.3 minutes for the No. 3 Column, with a resultant total empty-bed contact time of 87 minutes for the complete activated carbon system.

Since the influent to the No. 4 Carbon Column was a filtered, chemically-coagulated, activated sludge effluent, loss of head increased slowly and only infrequently was backwashing required. The lead contactor was backwashed daily, while the No. 3 Column was backwashed weekly. The backwash frequency was principally a matter of convenience for the plant operators, since the loss of head on either contactor rarely exceeded 0.6 meters (2 feet). Additionally, no problems with hydrogen sulfide formation in the activated carbon contactors were experienced.

Table 19 presents a water quality summary for the activated carbon contactors. A very significant reduction in total suspended solids, 88.2 percent, was observed; however, if the filter had been properly operated for the entire project, the solids loading to the carbon columns would have been greatly reduced. Turbidity was reduced from 4.8 FTU to 0.7 FTU by the carbon contactors, for an observed reduction of 85.4 percent.

Biologically refractory organic materials were reduced to very low levels by the carbon contactors. The product water COD averaged 3.3 mg/1, which represents an 80.6 percent reduction. Figure 29 is a time-series plot of the COD concentrations in the activated sludge effluent and the final product water from the No. 3 Carbon Column. The effect of the process upset in early December 1974 on the quality of the activated sludge effluent is quite obvious. However, only a very slight increase in the product water COD resulted from what one would normally consider a major perturbation in process control.

The effluent COD concentrations for the No. 3 Carbon Column are shown as a function of the influent COD concentrations for the No. 4 Carbon Column in Figure 30. As expected, these data exhibit relatively good correlation and predict a COD removal of approximately 75 percent.

With the exception of organic nitrogen, no significant changes in the various forms of nitrogen occurred as a result of carbon adsorption. Organic nitrogen concentrations were reduced by 66.7 percent, from 1.8 mg/1 to 0.6/mg 1.

Turbidity, total phosphorus, and soluble TOC data are shown for the activated carbon effluent in Figure 31. The peaks in total phosphorus coincide with increases in turbidity, which is to be expected.

The activated carbon contactors were very effective in reducing color from 11 to 0.3 units on the platinum-cobalt scale.

TABLE 19

WATER QUALITY SUMMARY FOR THE GRANULAR ACTIVATED CARBON CONTACTORS

Parameter	No. 1 Multimedia Filter Effluent (mg/l)	No. 4 Carbon Column Effluent (mg/l)	No. 3 Carbon Column Effluent (mg/l)	Reduction (percent)
TSS	17	2	2	88.2
BOD_5	--	--	1.3	--
COD	17	6.2	3.3	80.6
TOC	10.1	6.8*	5.8*	42.6
NH_3-N	3.3	2.1	2.6	21.2
Org.N	1.8	1.1	0.6	66.7
TKN	5.1	3.2	3.2	37.2
NO_2 & NO_3-N	6.0	6.1	5.9	1.7
NO_2-N	0.52	0.20	0.16	69.2
Total N	11.1	9.3	9.1	18.0
Total P	0.45	--	0.44	2.2
pH	6.8	6.8	6.9	--
Color (Pt-Co)	11	0.7	0.3	97.3
Alkalinity	--	227	--	--
Hardness	155	--	139	--
Turbidity (FTU)	4.8	--	0.7	85.4
F^-	1.15	--	1.18	--
Sp. Cond.	--	897	--	--
NaCl	--	130	128	--
SO_4	90	--	--	--
TDS	--	630	611	--
TPC/ml	8.7×10^3	330	710	91.8
TC/100 ml	1.5×10^3	440	320	78.7
FC/100 ml	4.3×10^2	37	23	94.6

*See comment on p 85

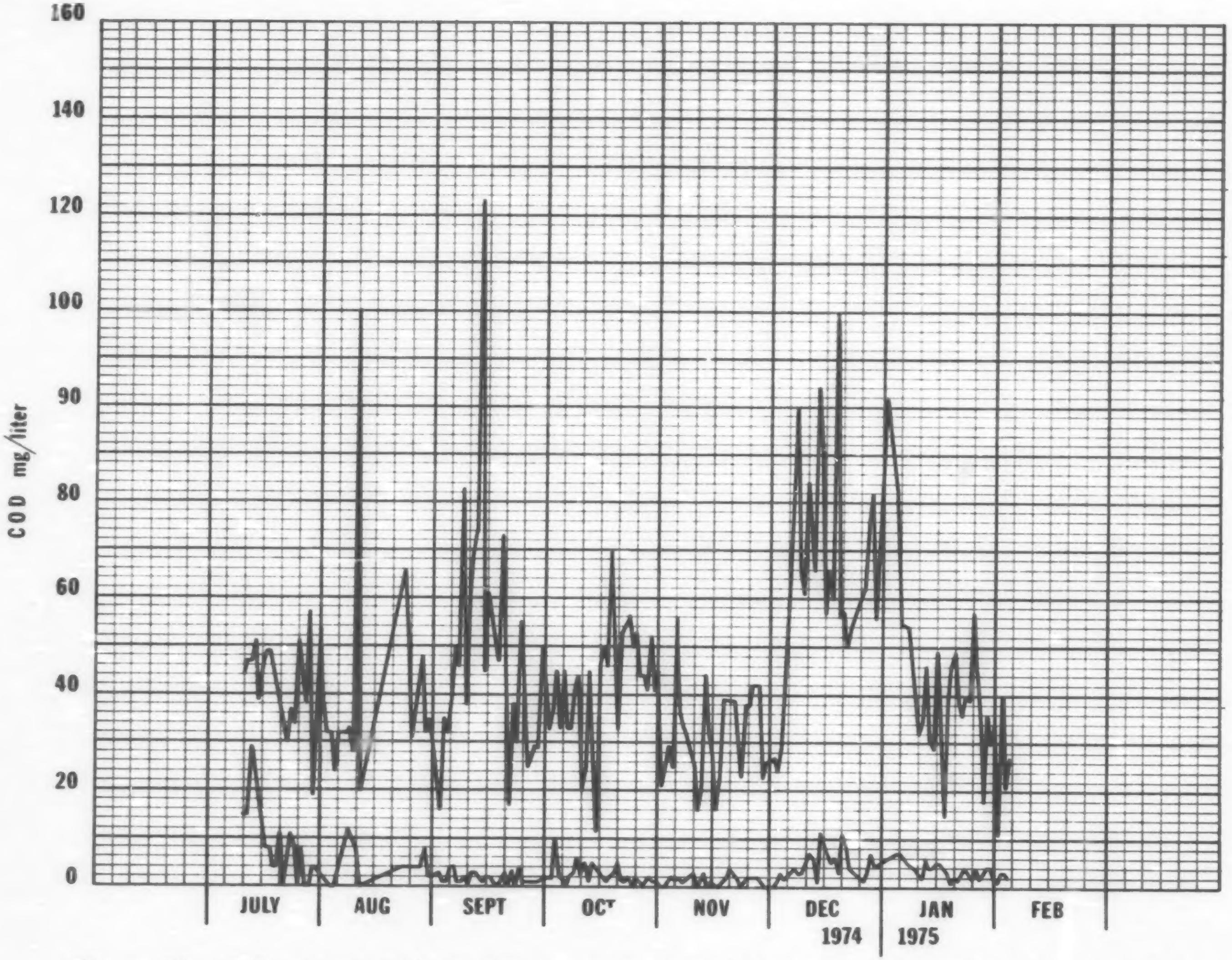

Figure 29. COD concentrations for the activated sludge effluent and the final product water.

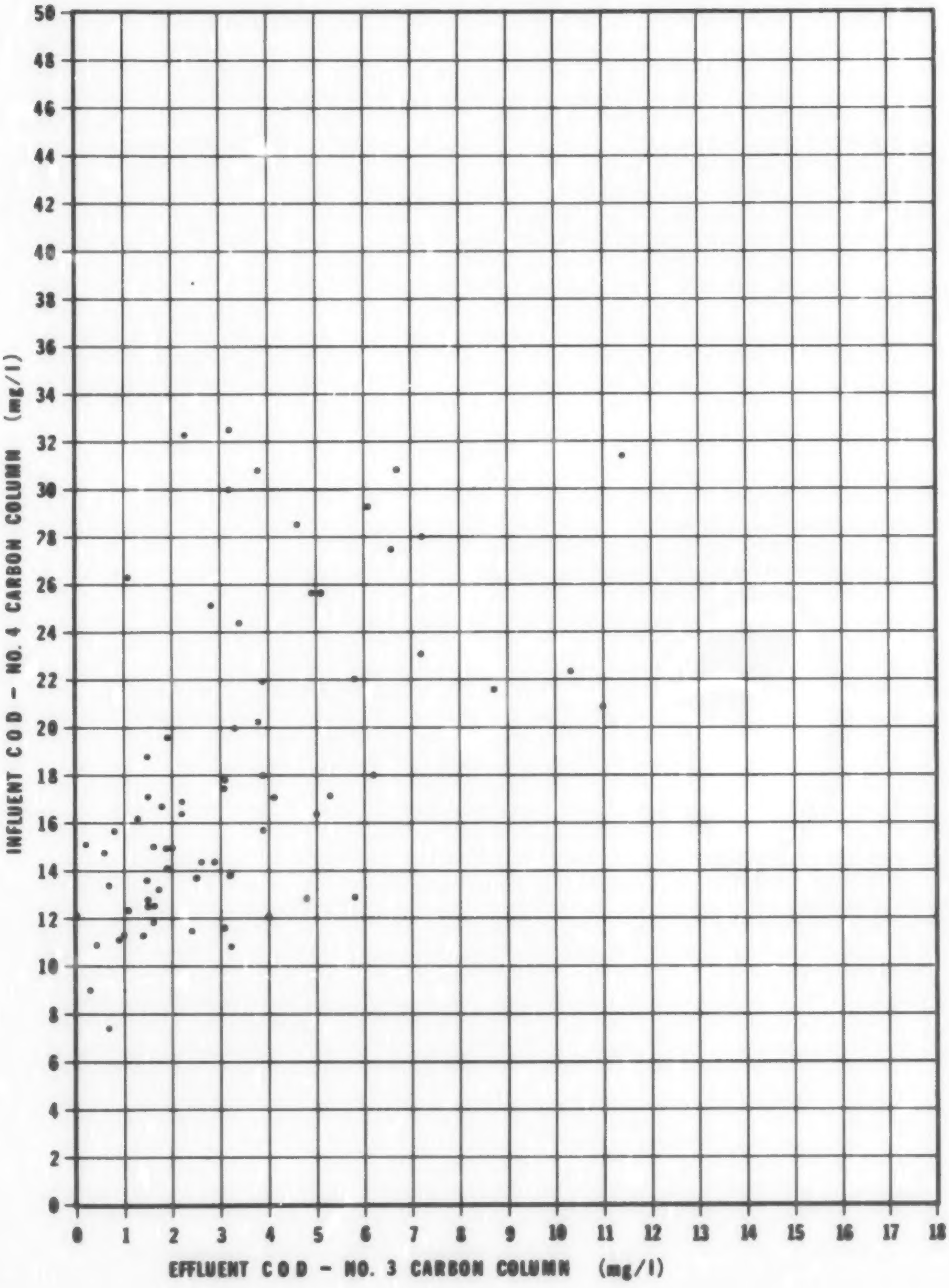

Figure 30. Product water COD as a function of influent COD to the activated carbon system.

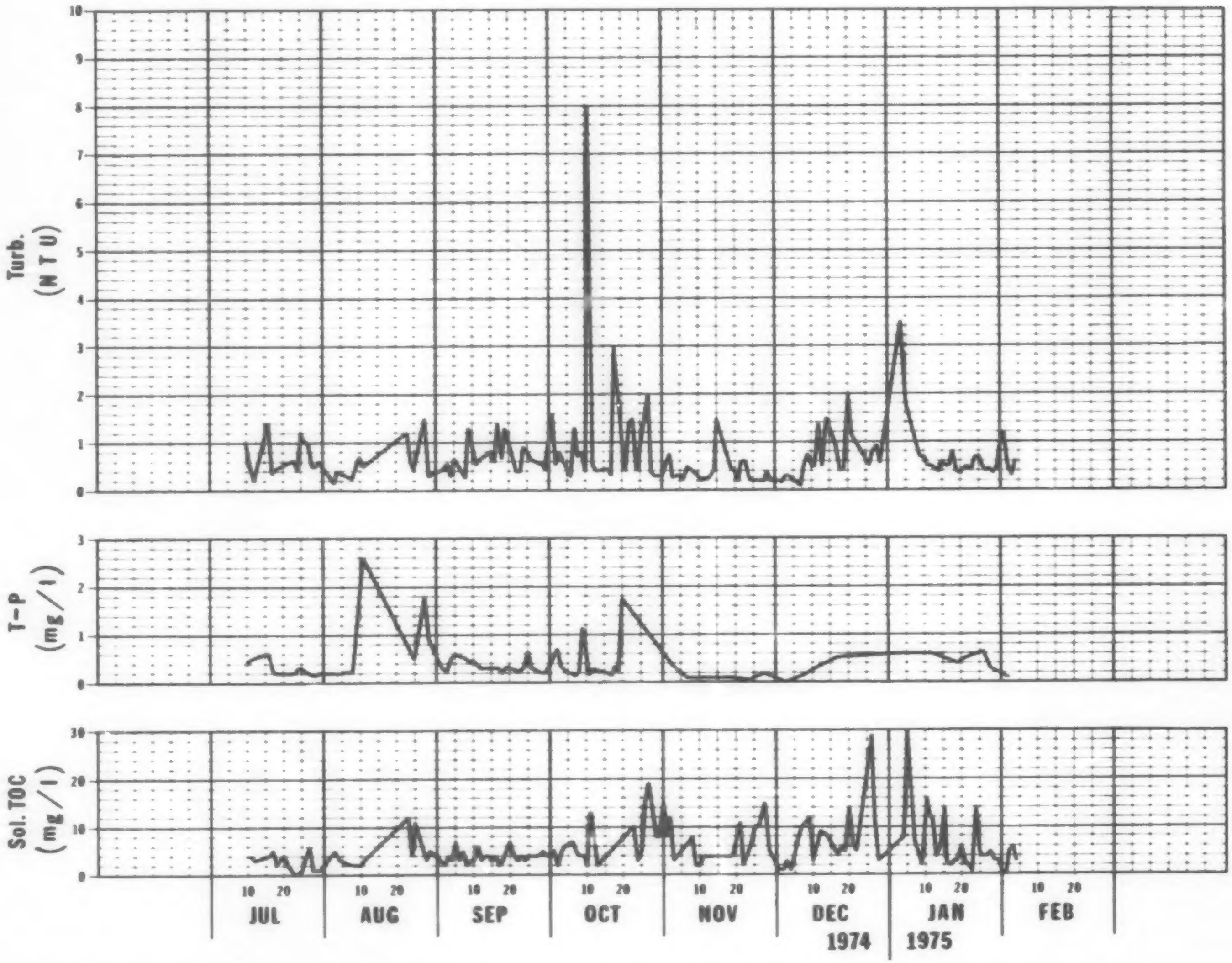

Figure 31. Turbidity, total phosphorus, and soluble TOC values for the product water.

SECTION VII

PROCESS RELIABILITY

When considering wastewater reclamation for potable reuse, process reliability must be of paramount concern. During this research effort the three operational problems described below perturbed the routine process control of the Demonstration Plant:

1. Failure of an operator to close a valve on schedule while wasting activated sludge caused a major loss of sludge and created a major and prolonged process upset in December 1974.
2. Improper backwashing of the mixed-media filter during the first months of the project resulted in two significant turbidity breakthroughs.
3. Mechanical problems with the hydrated lime feed system made pH control in the upflow clarifier very difficult.

Although these problems were totally undesirable when considered in terms of experimental design, the fact that they occurred makes the research effort more useful, since it permits evaluation of the stability of the overall treatment sequence.

ORGANIC MATERIALS

Logarithmic-normal probability distributions for the observed COD concentrations in the various process flows are shown in Figure 32. Log-normal probability graphs will generally plot data which are skewed to the right as reasonably straight lines, and for this reason are very useful in presenting water quality data obtained from wastewater effluents.

Figure 33 is a histogram of the COD values observed for the effluent from the No. 3 activated carbon contactor. These data are obviously skewed to the right, and a normal probability distribution for these data is shown in Figure 34.

Although the activated sludge process upset that occurred in early December 1974 had some effect on the quality of the product water, the impact was much less than one might have expected. In fact the three highest COD values measured on the product water (29, 15, and 15 mg/1) were observed during the first week of operation. Previous experience at the Demonstration Plant indicates that about two weeks are required before a new charge of granular activated carbon will consistently produce a high quality

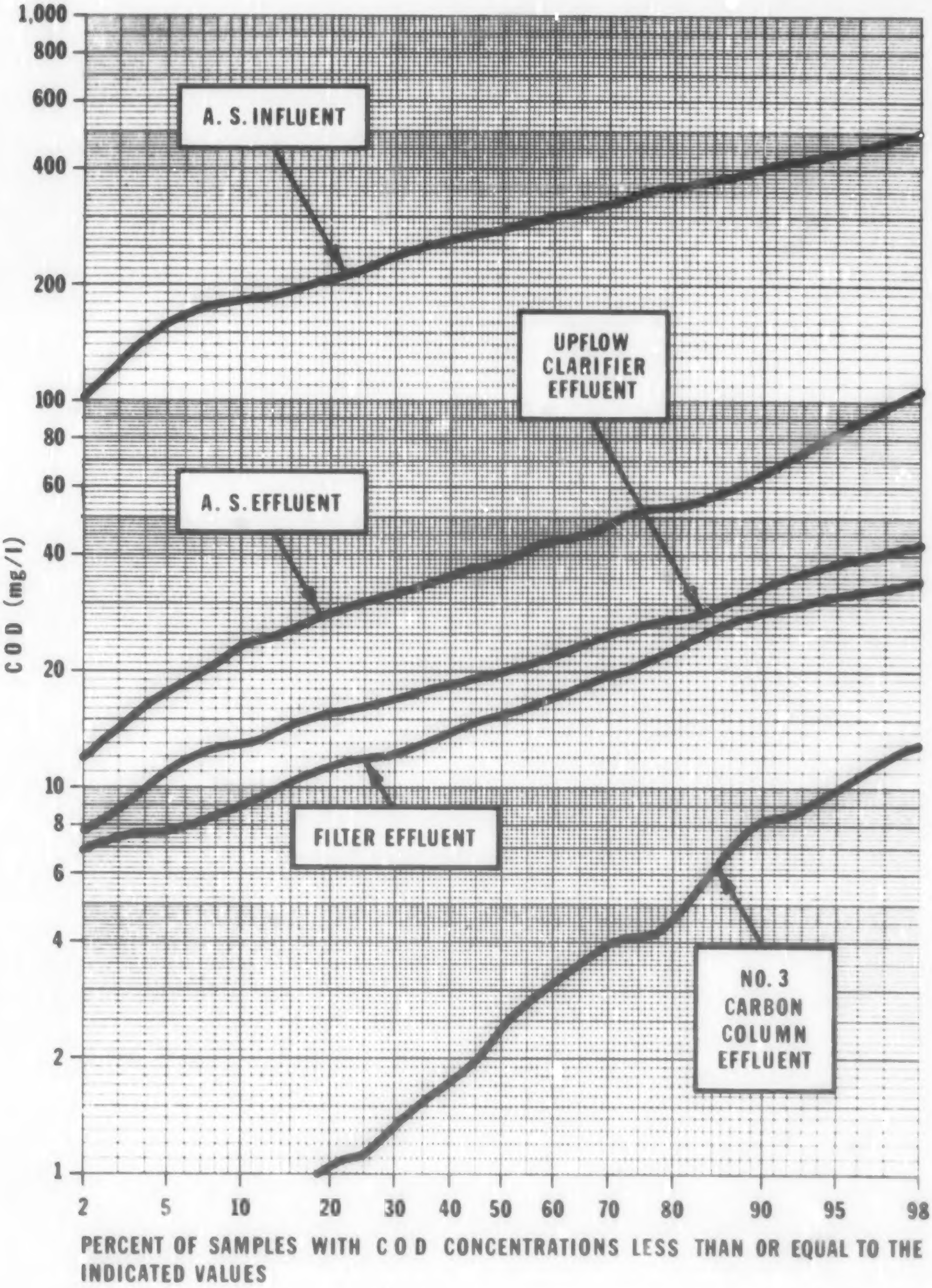

Figure 32. Log-normal frequency distribution for observed COD values.

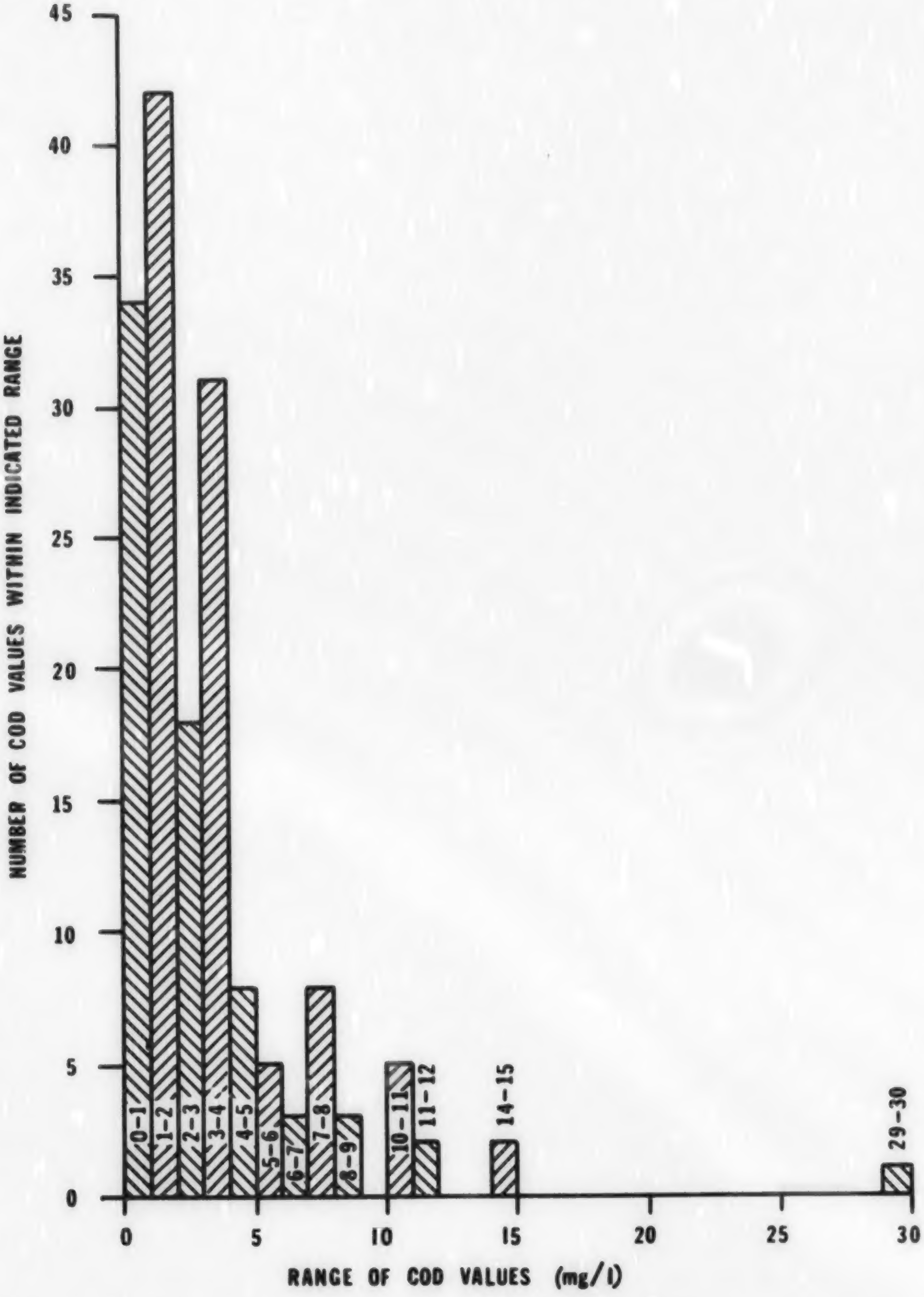

Figure 33. Histogram of product water COD concentrations.

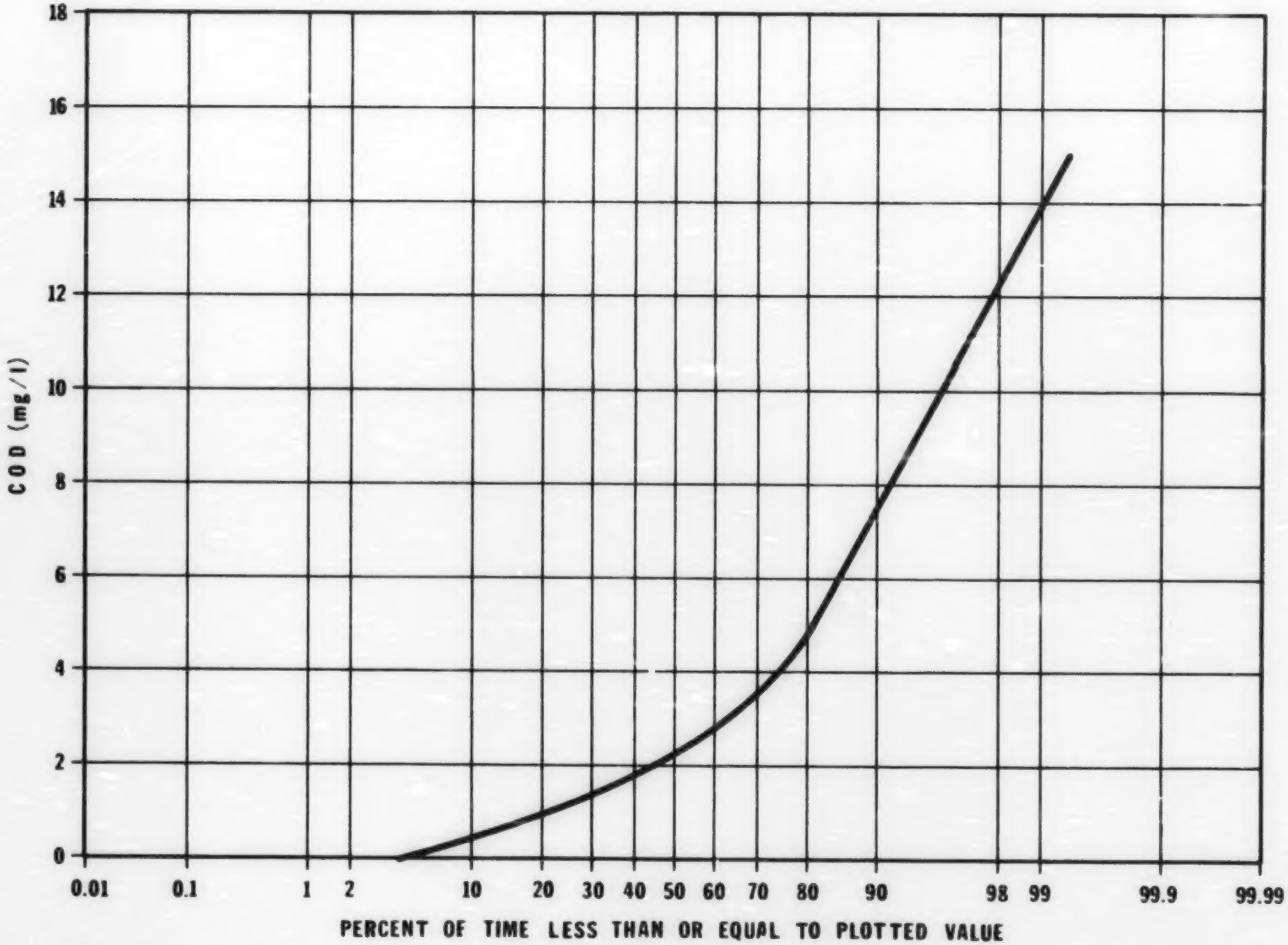

Figure 34. Normal probability distribution of COD values observed in the effluent of the No. 3 carbon column.

effluent. It is interesting to note that the six highest COD values were observed during the first two weeks following the start-up of the No. 3 contactor.

Soluble TOC data for the activated sludge influent and effluent, and total TOC data for the effluent from the No. 3 Carbon Column are shown in a log-normal probability distribution in Figure 35.

Mean and median COD and TOC values are compared for the different sample locations in Table 20. In most cases the median values are somewhat lower than the mean value, and since these data are positively skewed this condition is to be expected.

The TOC data obtained on the effluent from the No. 3 Carbon Column seem to be questionable. The TOC analyzer used for these determinations was calibrated such that full deflection was equivalent to a TOC concentration of 200 mg/l. Evaluation of BOD_5 : COD : TOC ratios obtained on previous research indicates that the COD values reported are correct, and that the TOC data are incorrect. The average COD and TOC ratio observed during this project was 2.08; hence, this ratio was used to calculate the mean and median TOC concentrations shown on the table of 2.8 and 1.9.

TOTAL SUSPENDED SOLIDS AND TURBIDITY

Log-normal probability distributions for total suspended solids and turbidity are shown in Figures 36 and 37, respectively. The effect of the suspended solids and turbidity breakthrough that occurred on the No. 1 Filter is obvious. However, since the gravity-flow carbon contactors function as relatively good filters the quality of the product water remained relatively good.

The turbidity in the effluent from the No. 3 Carbon Column exceeded 1.0 FTU in twenty percent of the samples, but only exceeded 3.0 FTU in three percent of the samples. Filtration aids, such as polyelectroytes or alum, were not used during this project, and their use would have improved product water quality when difficulties with the filter were being experienced.

TOTAL PHOSPHORUS

The observed total phosphorus concentrations are presented in Figure 38 as log-normal probability distributions. The median total phosphorus concentration in the activated sludge influent of 8.4 mg/l was reduced to 6.2 mg/l by biological treatment.

The effluent from the upflow clarifier had a total phosphorus concentration that exceeded 2.6 mg/l in ten percent of the samples. The extreme variability in the observed phosphorus concentrations can be directly related to problems in controlling the lime feed to the upflow clarifier and switching the ferric chloride feed from the upflow clarifier to the activated sludge process.

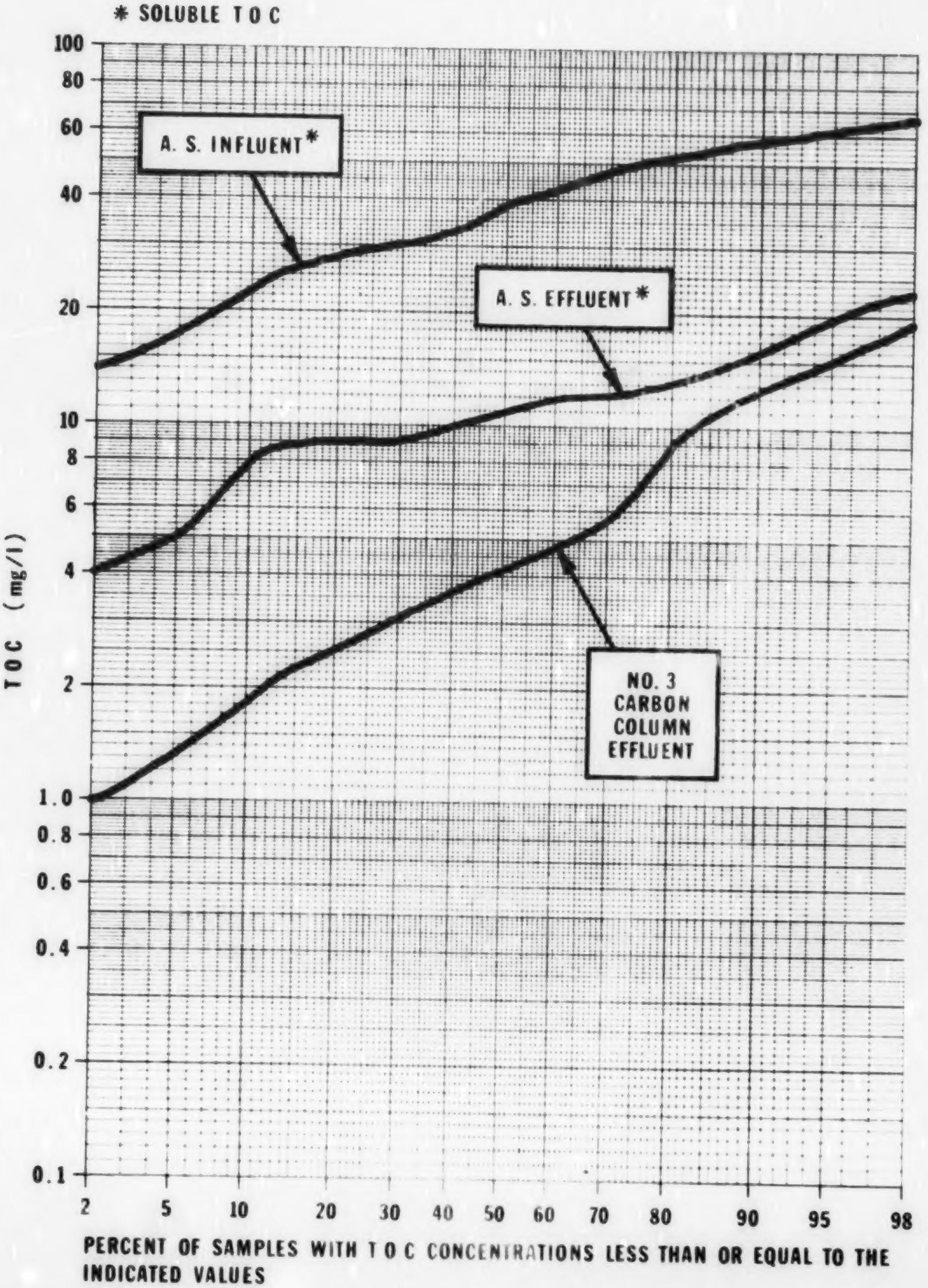

Figure 35. Log-normal frequency distribution of observed TOC concentrations.

TABLE 20

COMPARISON OF MEAN AND MEDIAN COD AND TOC CONCENTRATIONS FOR DIFFERENT PROCESS FLOWS

SAMPLE LOCATION	COD (mg/1)		TOC (mg/1)	
	Mean	Median	Mean	Median
Activated Sludge Influent	281	276	39*	39*
Activated Sludge Effluent	44	39	11*	11*
Upflow Clarifier Effluent	22	20	9	8
Recarbonation Basin Effluent	24	17	11	9
No. 1 Mixed Media Filter Effluent	17	16	10	9
No. 3 Carbon Column Effluent	3.3	2.2	5.8	4
			(2.8)	(1.9)

*Soluble TOC

( ) - Calculated TOC values

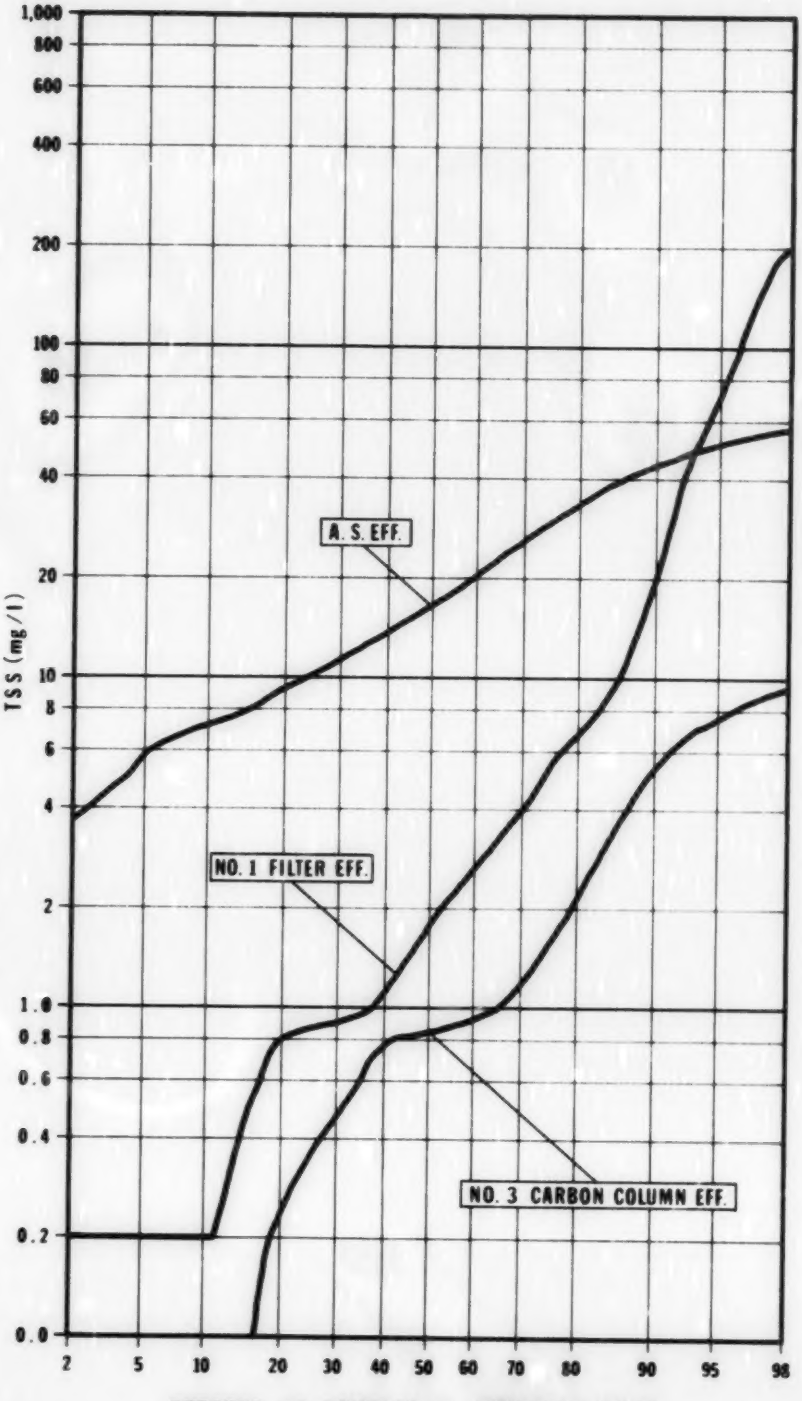

Figure 36. Log-normal frequency distribution of observed TSS concentrations.

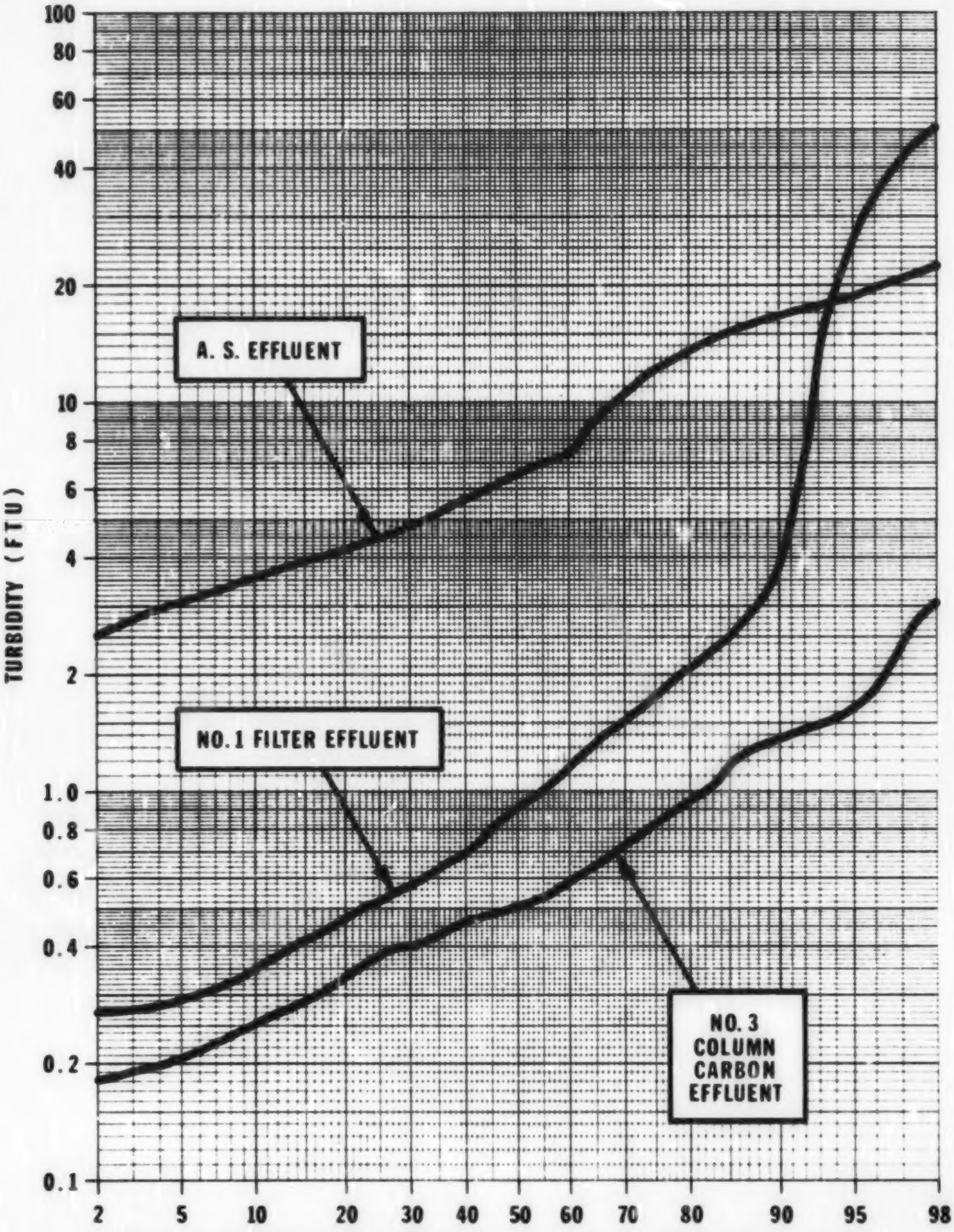

Figure 37. Log-normal probability distribution of the observed turbidity values.

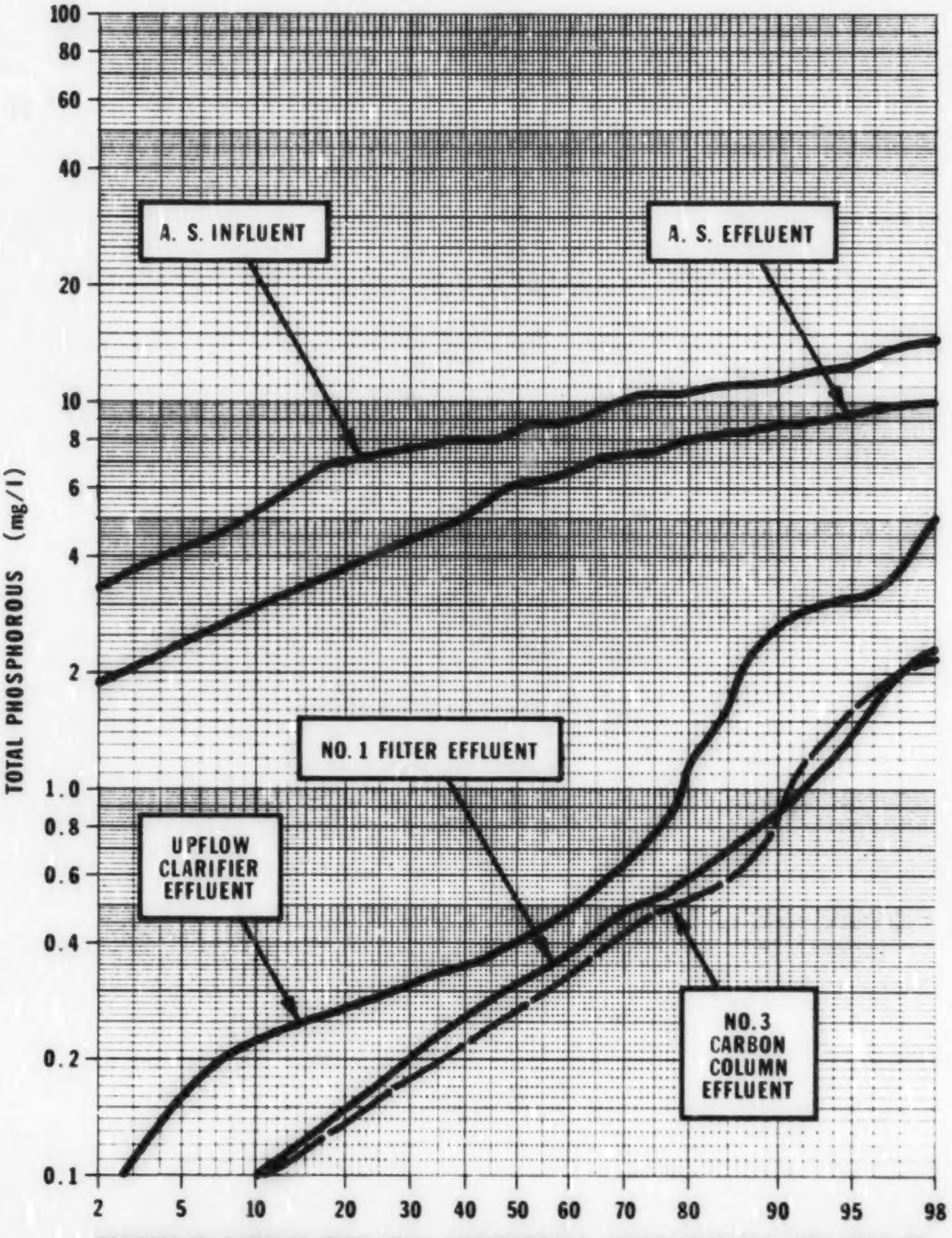

Figure 38. Log-normal frequency distribution of observed total phosphorus concentrations.

The effluent from the No. 3 Carbon Column had very low phosphorus concentrations. Two samples had total phosphorus concentrations exceeding 2.0 mg/l, and only five samples exceeded 1.0 mg/l.

NITROGEN COMPOUNDS

Log-normal probability distributions for ammonia nitrogen, nitrite-nitrate nitrogen, and organic nitrogen are shown in Figures 39, 40, and 41, respectively. Nitrification was not achieved consistently during this project as a result of difficulties encountered with the oxygen transfer equipment and operator error. The NH_3-N concentration in the activated sludge effluent exceeded 2.0 mg/l in forty percent of the samples, although the median concentration was 0.8 mg/l. No significant changes in ammonia nitrogen concentrations were observed in the processes following the activated sludge system.

The median nitrite-nitrate concentration observed in the product water was 6.4 mg/l, and the nitrite-nitrate concentration exceeded 10 mg/l in only eight percent of the samples.

The median organic nitrogen concentration in the activated sludge effluent was 2.8 mg/l, and the AWT processes (principally that of activated carbon) very significantly reduced the median organic nitrogen concentration to 0.45 mg/l.

METALS

Fifteen special weekly composite samples were analyzed for a total of thirteen different metals at four different points in the treatment sequence. These data are summarized in Table 21.

SILVER

Silver was present in such low concentrations that analysis for this metal was terminated after the fifth weekly composite sample. At the low silver concentrations observed in the City of Dallas wastewater, no significant change in the concentration of this metal occurred.

ARSENIC

Observed arsenic concentrations for the study period are shown in Figure 42. Total removal of arsenic was excellent, averaging almost 86 percent. High pH lime coagulation and filtration were the most important processes effecting the removal of arsenic.

BORON

Boron concentrations are shown in Figure 43, and obviously no significant removal of boron was observed during this study.

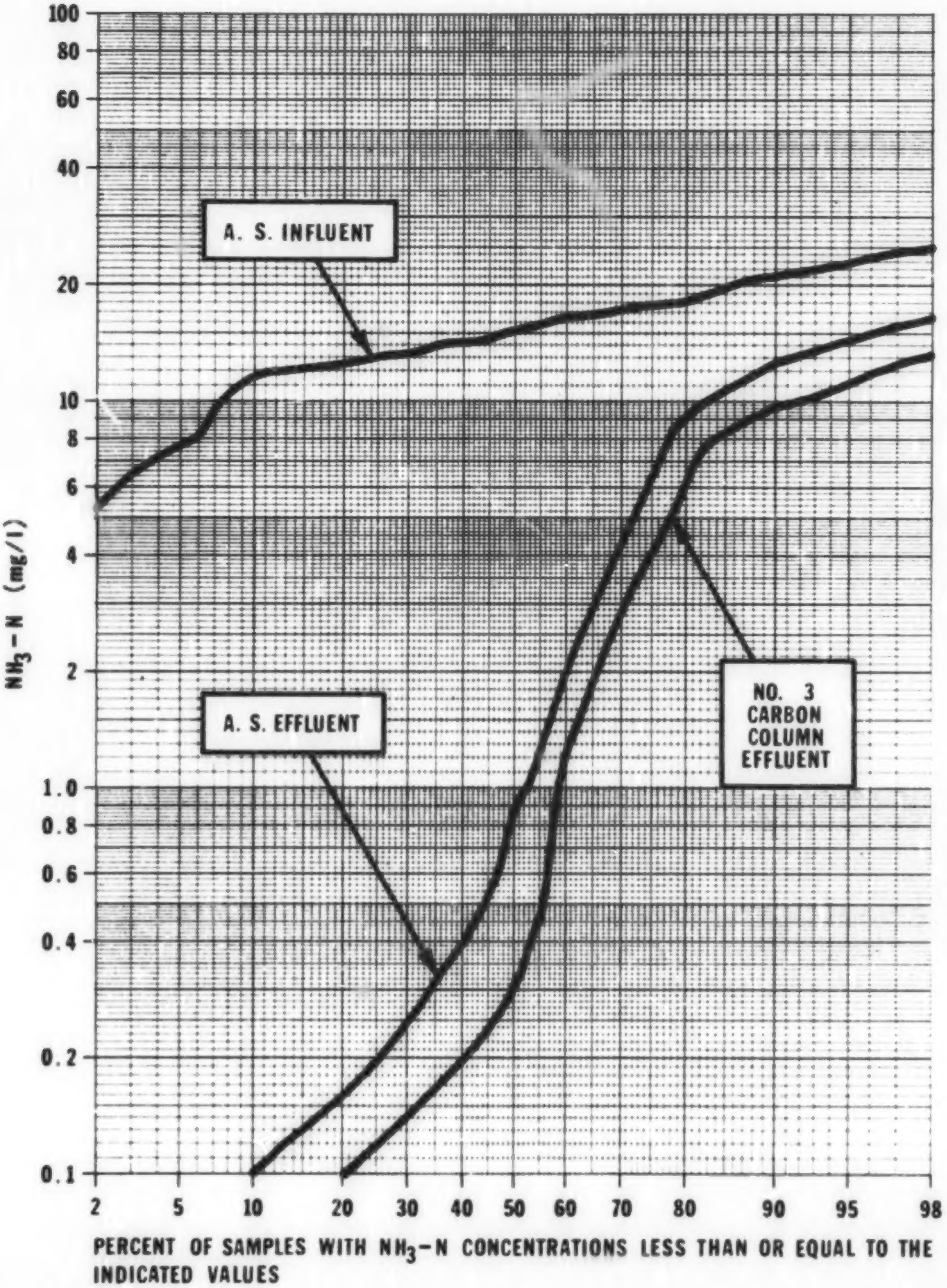

Figure 39. Log-normal frequency distribution of NH_3-N concentrations.

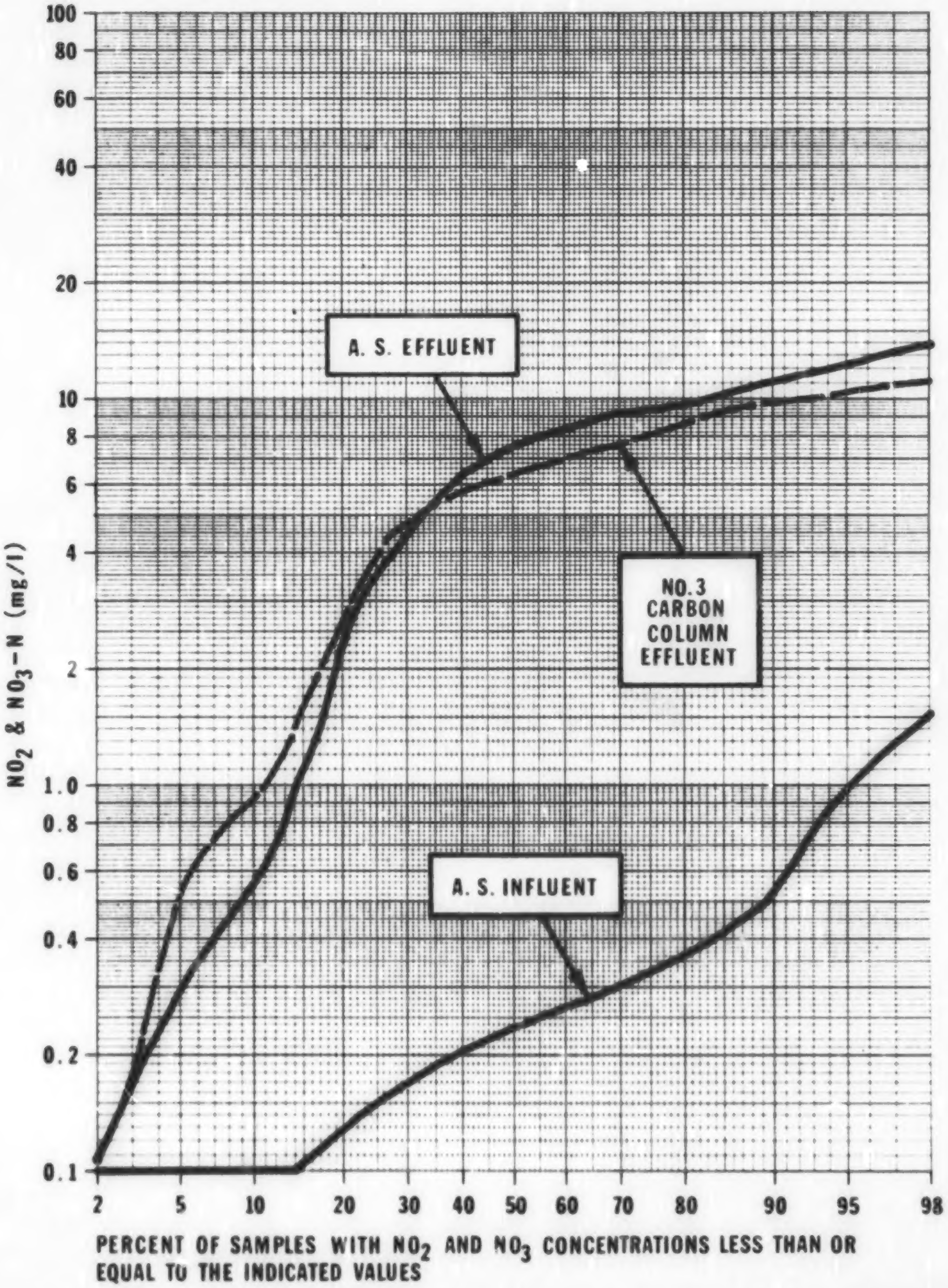

Figure 40. Log-normal frequency distribution of NO$_2$ & NO$_3$-N concentrations.

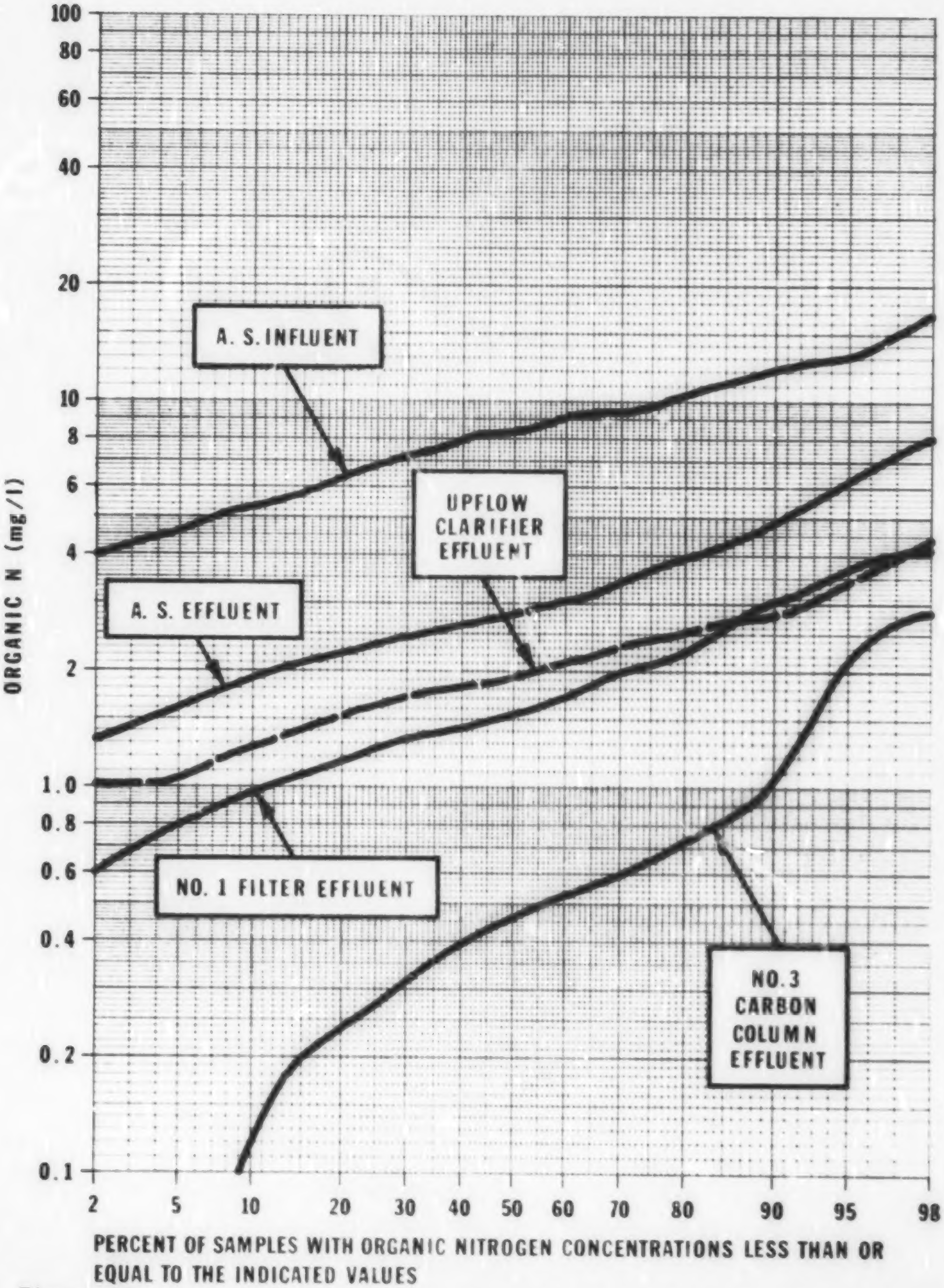

Figure 41. Log-normal frequency distribution of organic nitrogen concentrations.

TABLE 21

MEAN METALS CONCENTRATIONS OBSERVED IN WEEKLY COMPOSITE SAMPLES

Metal	A. S. Influent (mg/l)	A. S. Effluent (mg/l)	*Reduction by Biological Treatment (percent)*	No. 1 Filter Effluent (mg/l)	*Reduction by Chemical Treatment & Filtration (percent)*	No. 3 Carbon Column Effluent (mg/l)	*Reduction by Carbon Absorption (percent)*	*Total Observed Reduction (percent)*
Ag	0.0024	0.0026	*Inc.*	0.004	*Inc.*	0.0024	*40*	*0*
As*	20.9	17.0	*18.7*	4.1	*75.9*	3.0	*26.8*	*85.6*
B	0.29	0.30	*Inc.*	0.29	*3.3*	0.27	*6.9*	*6.9*
Ba	0.18	0.12	*33.3*	0.14	*Inc.*	0.14	*0*	*22.2*
Cd	0.012	0.005	*58.3*	0.003	*40.0*	0.002	*33.3*	*83.3*
Cr	0.077	0.027	*64.9*	0.012	*55.5*	0.020	*Inc.*	*74.0*
Cu	0.141	0.029	*74.4*	0.091	*Inc.*	0.046	*49.5*	*67.4*
Fe	0.65	0.59	*9.2*	0.12	*79.7*	0.10	*16.7*	*84.6*
Hg*	0.297	0.164	*44.8*	0.139	*15.2*	0.512	*Inc.*	*Inc.*
Mn	0.071	0.041	*42.3*	0.011	*73.2*	0.011	*0*	*84.5*
Pb	0.072	0.034	*52.8*	0.034	*0*	0.035	*Inc.*	*51.4*
Se*	4.4	2.9	*34.1*	0.5	*82.8*	0.9	*Inc.*	*79.5*
Zn	0.113	0.063	*44.2*	0.068	*Inc.*	0.063	*7.3*	*44.2*

* - micrograms per liter

Inc. - Increase

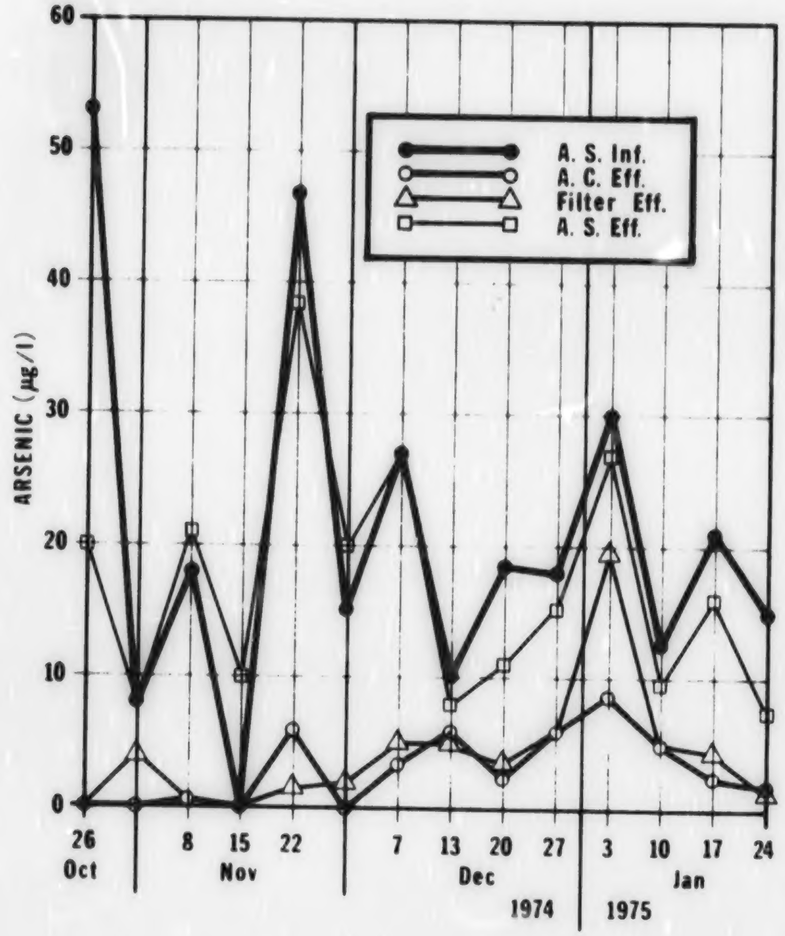

Figure 42. Observed variations in arsenic concentrations.

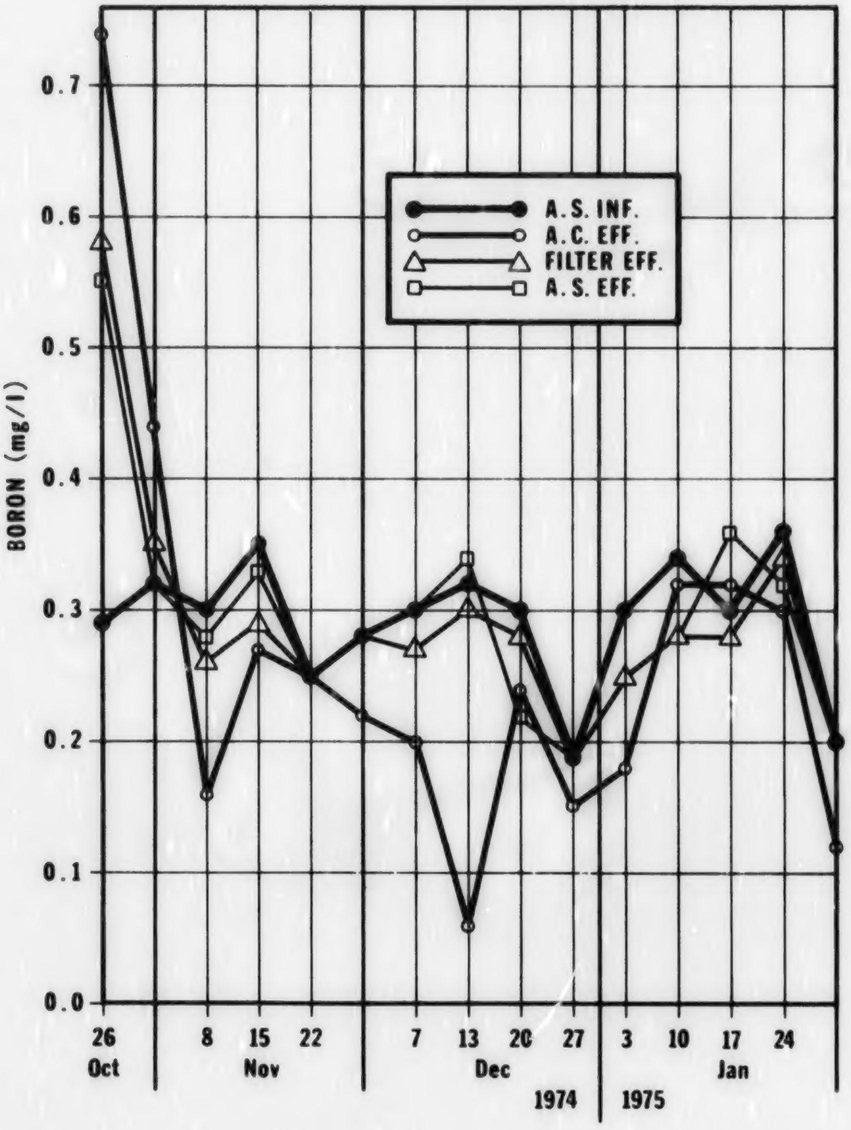

Figure 43. Observed variations in boron concentrations.

BARIUM

Barium is a relatively refractory metal, and only a 22.2 percent total reduction was observed. All of the observed reduction occurred in the activated sludge process. Barium concentrations are shown in Figure 44.

CADMIUM

Total cadmium removal was good, averaging 83.3 percent. The activated sludge process reduced the mean cadmium concentration from 0.012 mg/l to 0.005 mg/l, and was the most significant process with respect to the removal of this metal, as indicated in Figure 45.

CHROMIUM

The observed chromium concentrations are shown in Figure 46, and appear well behaved with the exception of the samples collected during the week of December 27, 1974 through January 2, 1975. The samples on the filter effluent, and most obviously the effluent from the No. 3 Carbon Column, exhibit peaks that appear to indicate sample contamination with acid-dichromate. Chromium removal was excellent, averaging 74 percent. Both the biological and the physical-chemical processes were responsible for significant chromium removal.

COPPER

As indicated in Figure 47, copper reductions were quite significant during this study. The observed total reduction was 67.4 percent, and the activated sludge process was responsible for the greatest removal, reducing the mean concentration from 0.141 mg/l to 0.029 mg/l.

IRON

Iron reductions were quite significant, averaging 84.6 percent. The two peaks in the activated sludge effluent, shown in Figure 48, that occurred during the ninth and tenth weeks were the result of ferric chloride feed to the activated sludge process.

MERCURY

Mercury concentrations are shown in Figure 49, and these data are very erratic. No significant removal of mercury was observed during this research effort;in fact, an increase of about 0.2 micrograms per liter was observed, although the activated sludge process did reduce the mercury concentration by about 45 percent.

MANGANESE

Manganese removal was very good, averaging 84.5 percent for the project period. The concentrations observed in the weekly composite samples are shown in Figure 50. The data for the effluents from the No. 1 filter and the No. 3 Carbon Column are very well behaved and average 0.011 mg/l. The

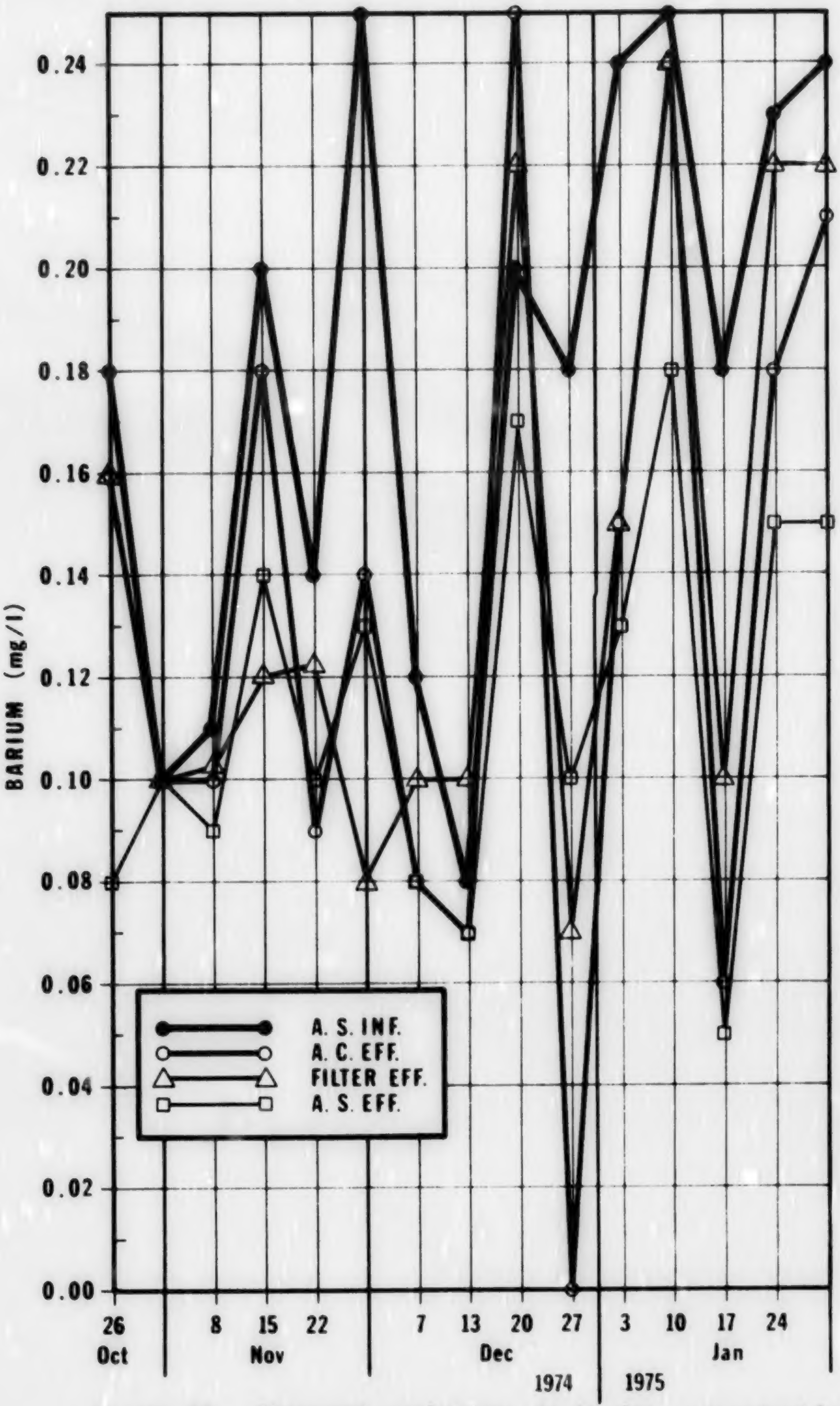

Figure 44. Observed variations in barium concentrations.

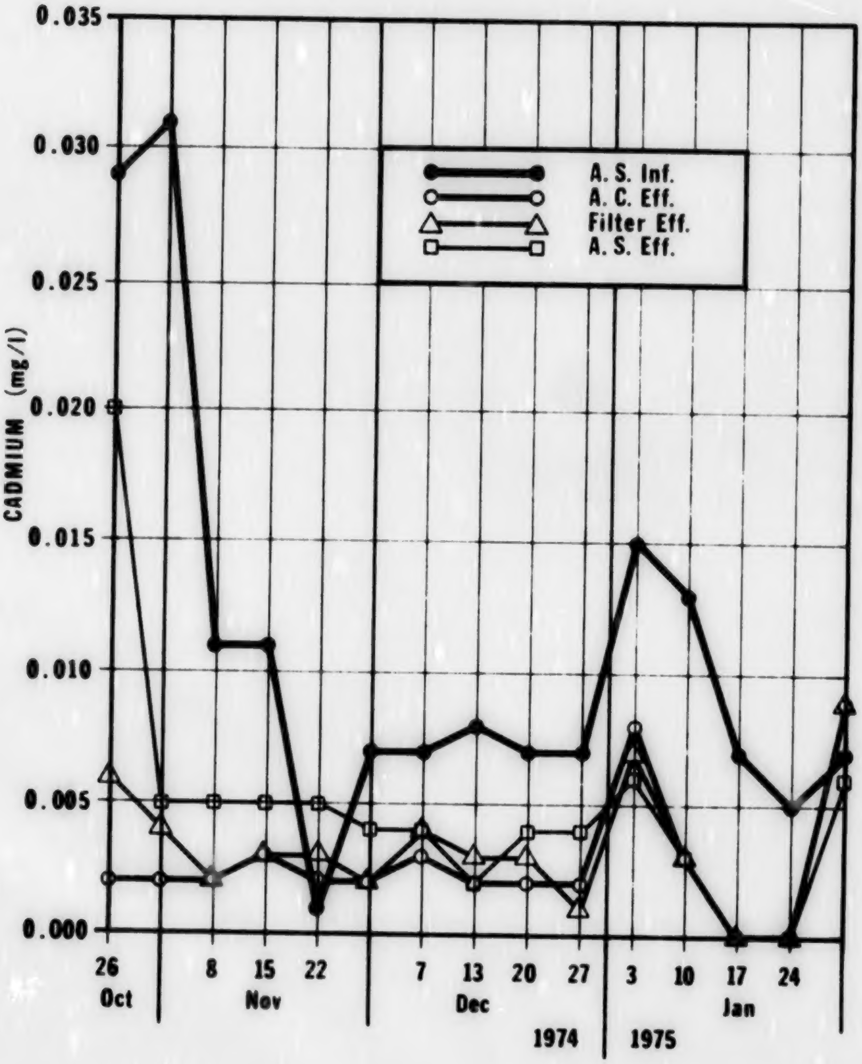

Figure 45. Observed variations in cadmium concentrations.

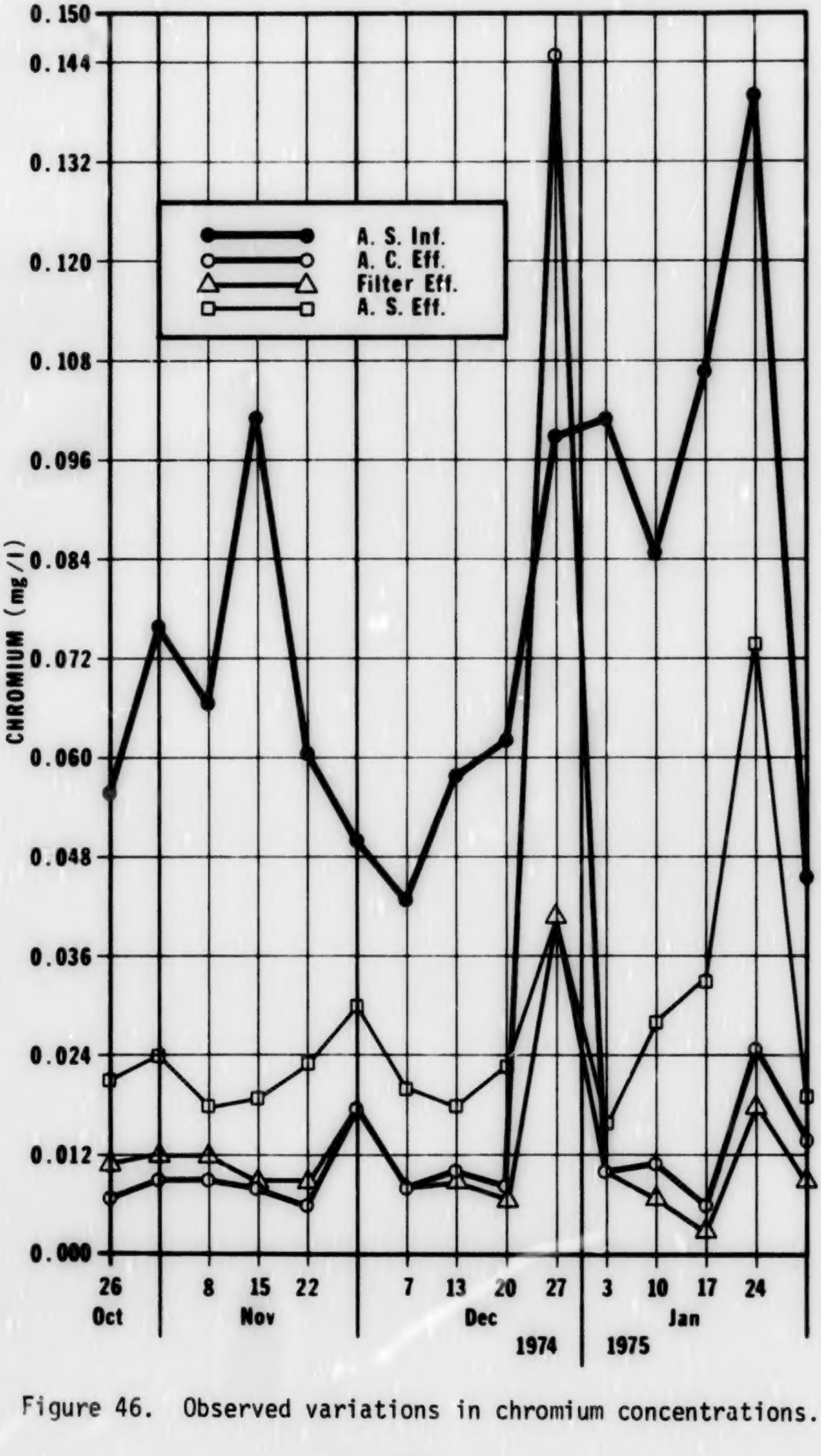

Figure 46. Observed variations in chromium concentrations.

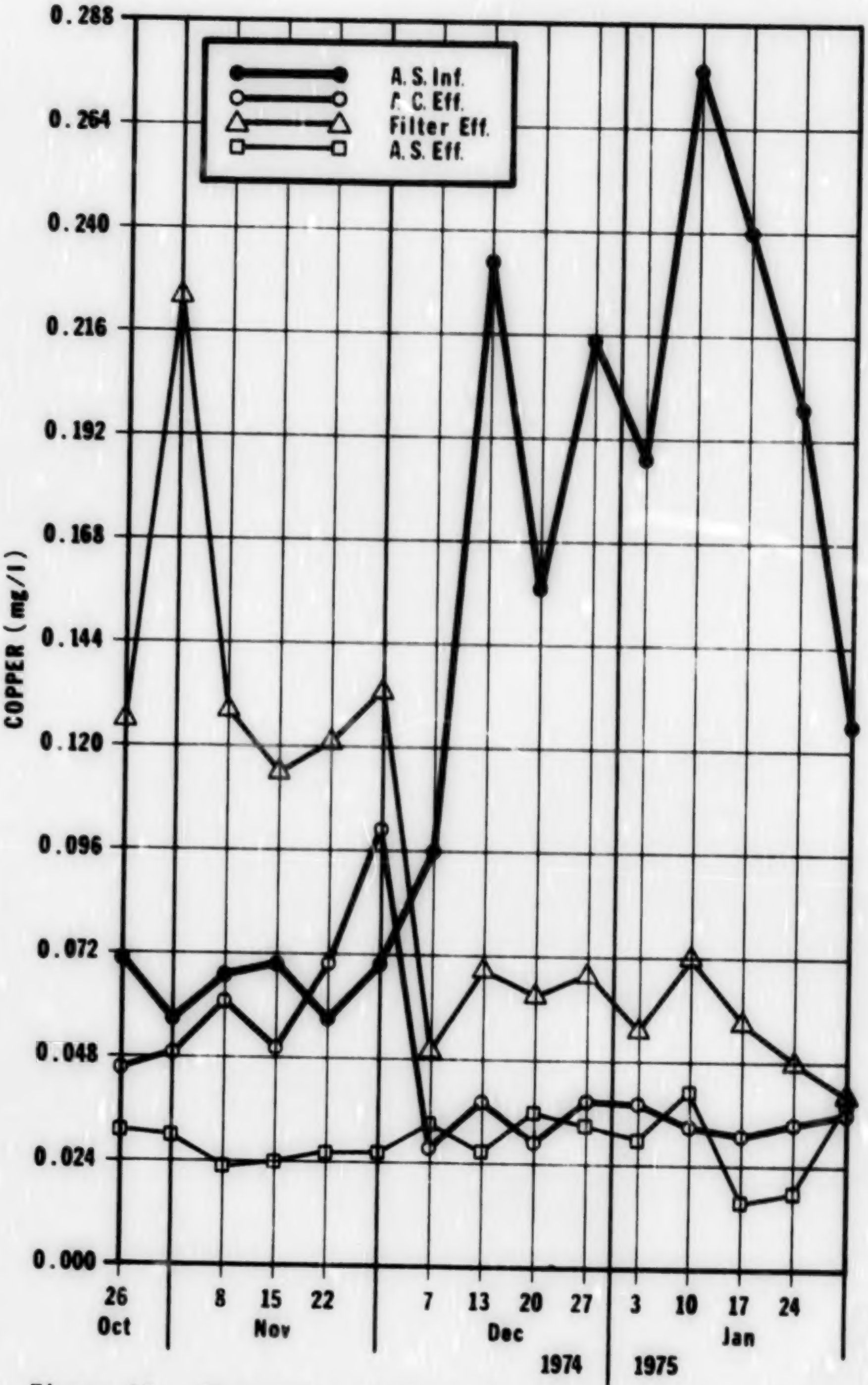

Figure 47. Observed variations in copper concentrations.

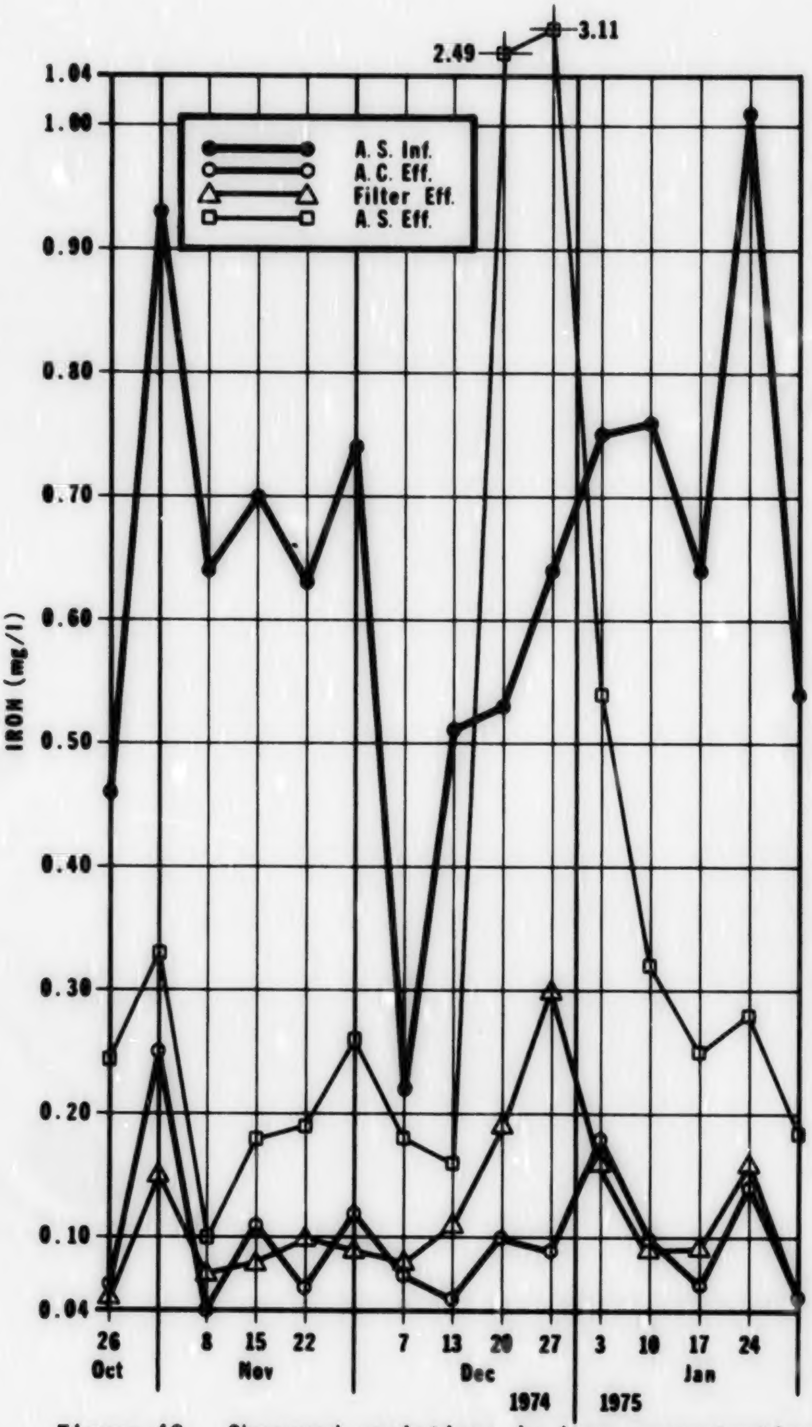

Figure 48. Observed variations in iron concentrations.

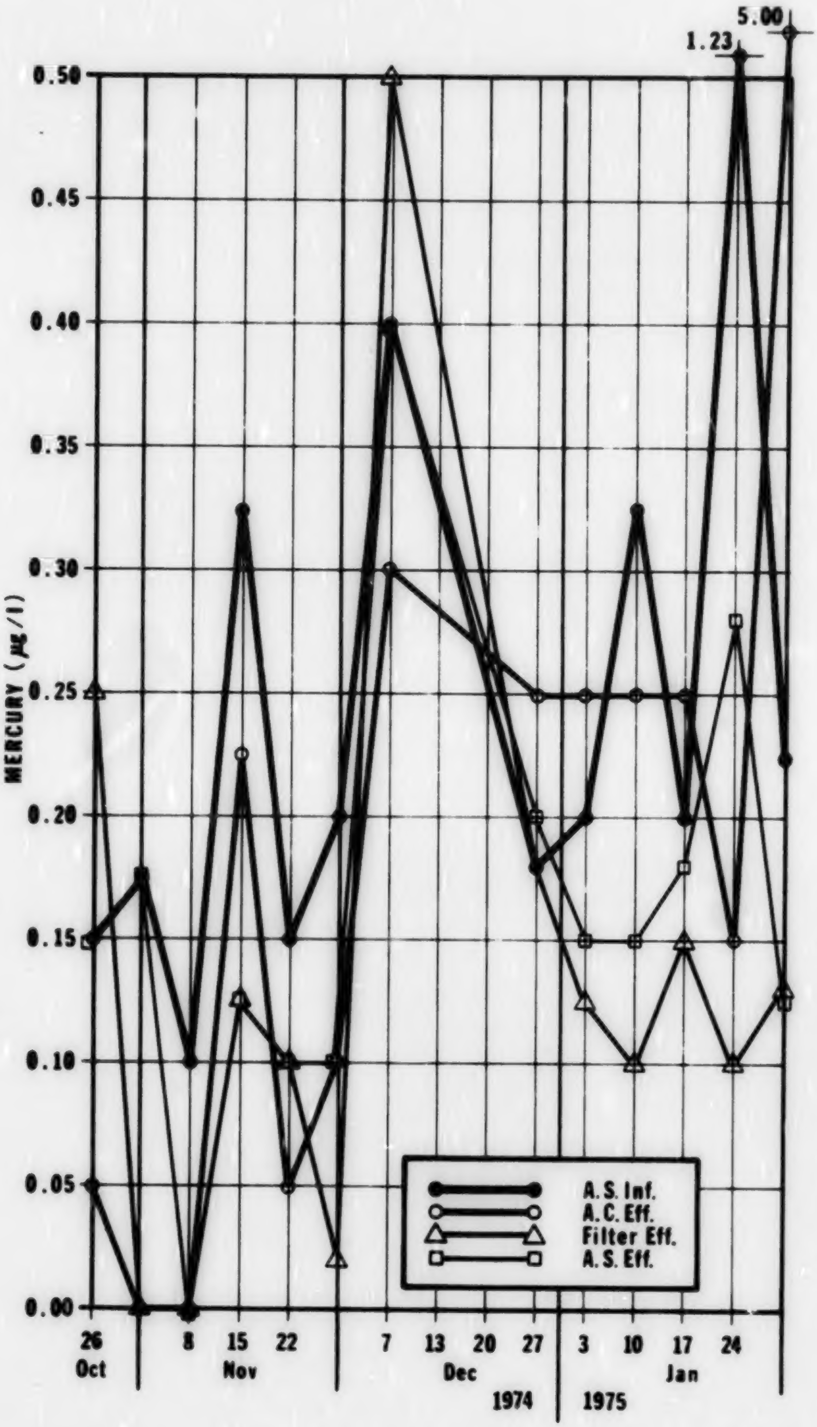

Figure 49. Observed variations in mercury concentrations.

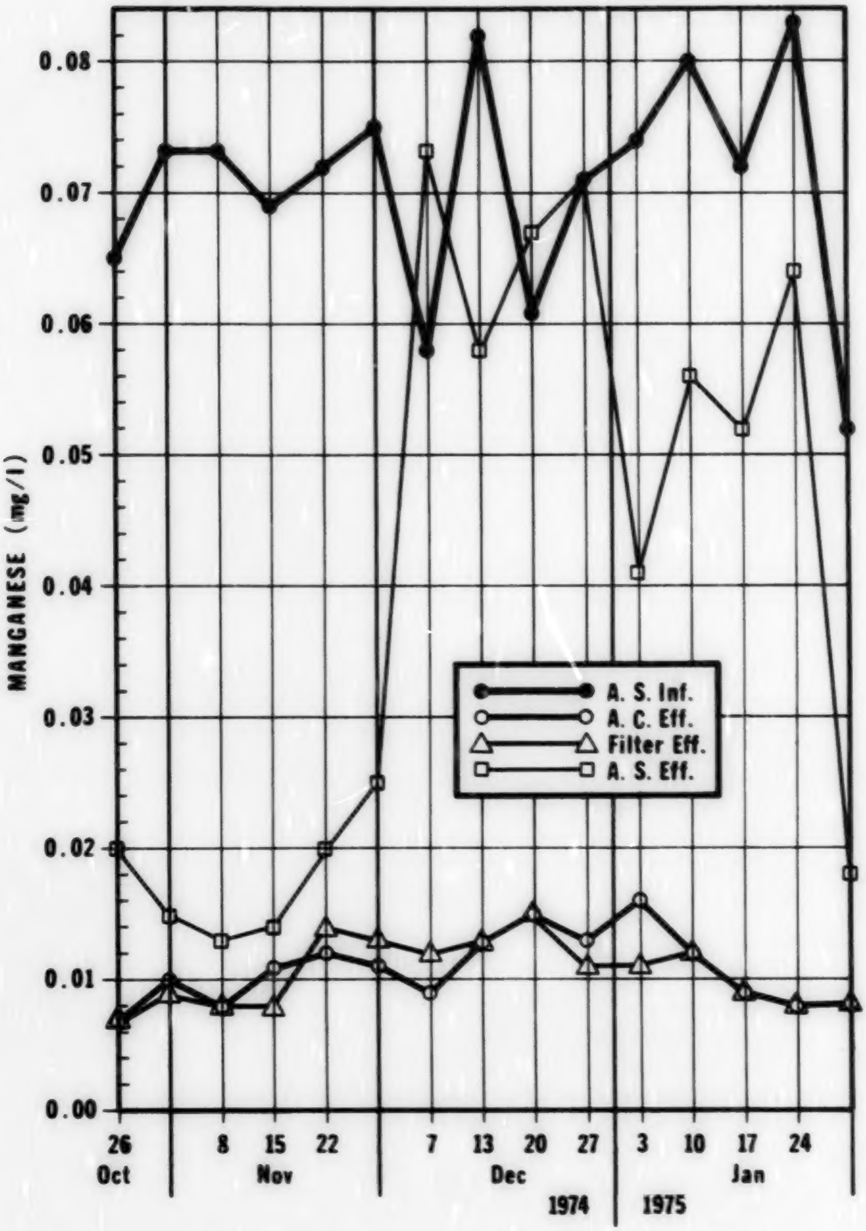

Figure 50. Observed variations in manganese concentrations.

activated sludge is quite variable, and a significant peak develops at precisely the same time the major process upset occurred. The manganese concentration in the activated sludge effluent then decreases as the biomass in the activated sludge system becomes re-established.

LEAD

The lead concentrations observed during this study were somewhat erratic, as the data in Figure 51 indicate. The only significant lead removal observed was the result of biological processes; the physical-chemical processes were rather ineffectual in altering lead concentrations.

SELENIUM

As the data in Figure 52 indicate, selenium is present in the City of Dallas wastewater at very low concentrations. This metal's concentration was reduced by an average of 79.5 percent, and the physical-chemical processes were particularly effective.

ZINC

The changes in zinc concentrations observed during this research are difficult to quantify because the recarbonation basin was a galvanized steel tank. The data shown in Figure 53 indicate that a relatively constant 44 percent zinc reduction could be anticipated from the activated sludge process. As a result of zinc pick-up from the recarbonation basin it is impossible to make any definitive statement with respect to the physical-chemical processes.

COMPLIANCE WITH THE NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

The objective of this research effort was the production of a product water that was of potable quality, and for the purposes of defining potable water quality, those water quality criteria presented in the National Interim Primary Drinking Water Regulations will be utilized.

Figure 54 presents a graphical comparison between the water quality criteria established in the NIPDWR (excepting coliforms) and the arithmetic means for the various water quality parameters monitored in the product water from the No. 3 granular carbon contactor.

Nitrate Nitrogen

During this study the combined nitrite-nitrate nitrogen concentration averaged 5.9 mg/l, and the nitrite nitrogen concentration averaged 0.16 mg/l. Nitrate nitrogen concentrations were equal to, or exceeded, the 10 mg/l standard in approximately eight percent of the samples.

Due to the instability of the activated sludge process during this study, it is quite likely that higher nitrate nitrogen concentrations would

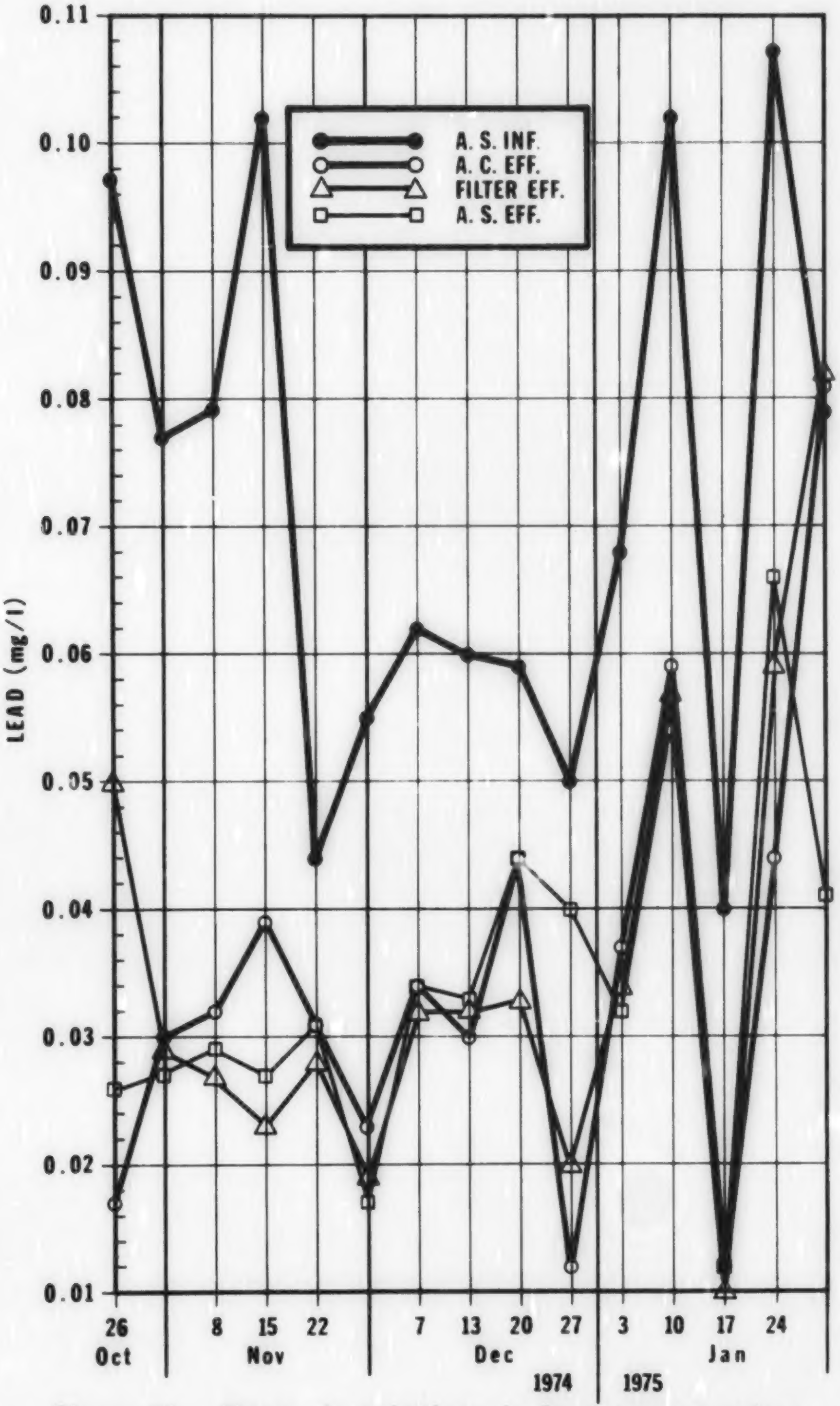

Figure 51. Observed variations in lead concentrations.

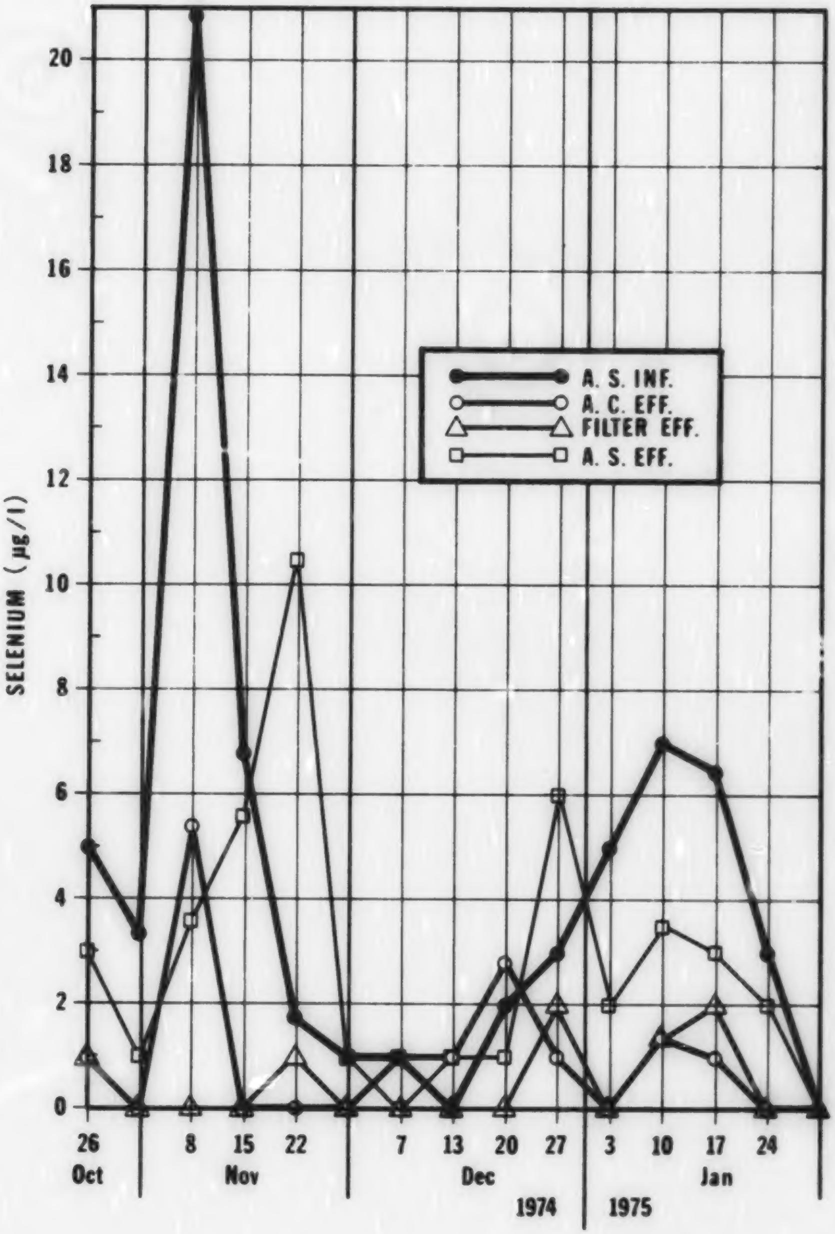

Figure 52. Observed variations in selenium concentrations.

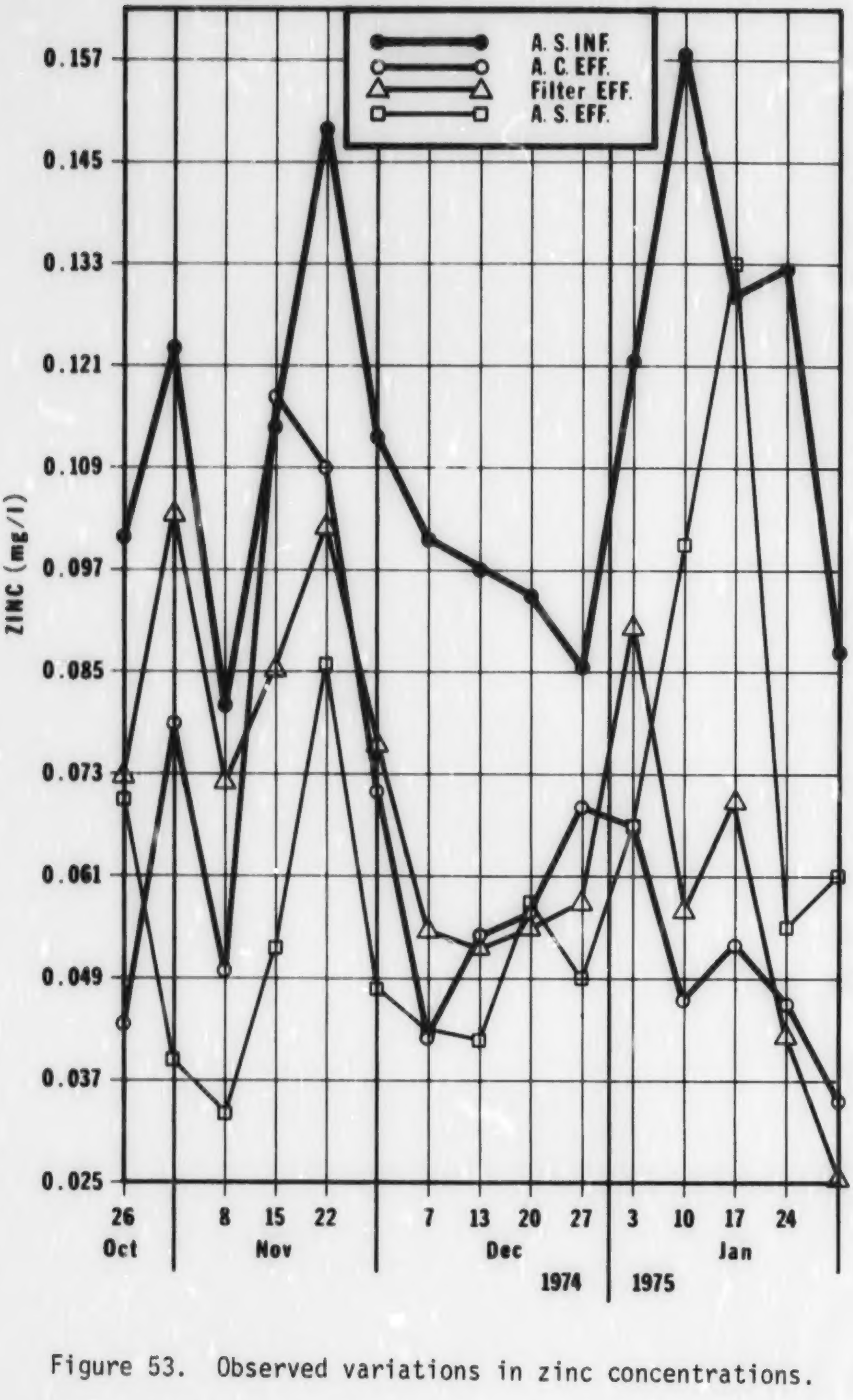

Figure 53. Observed variations in zinc concentrations.

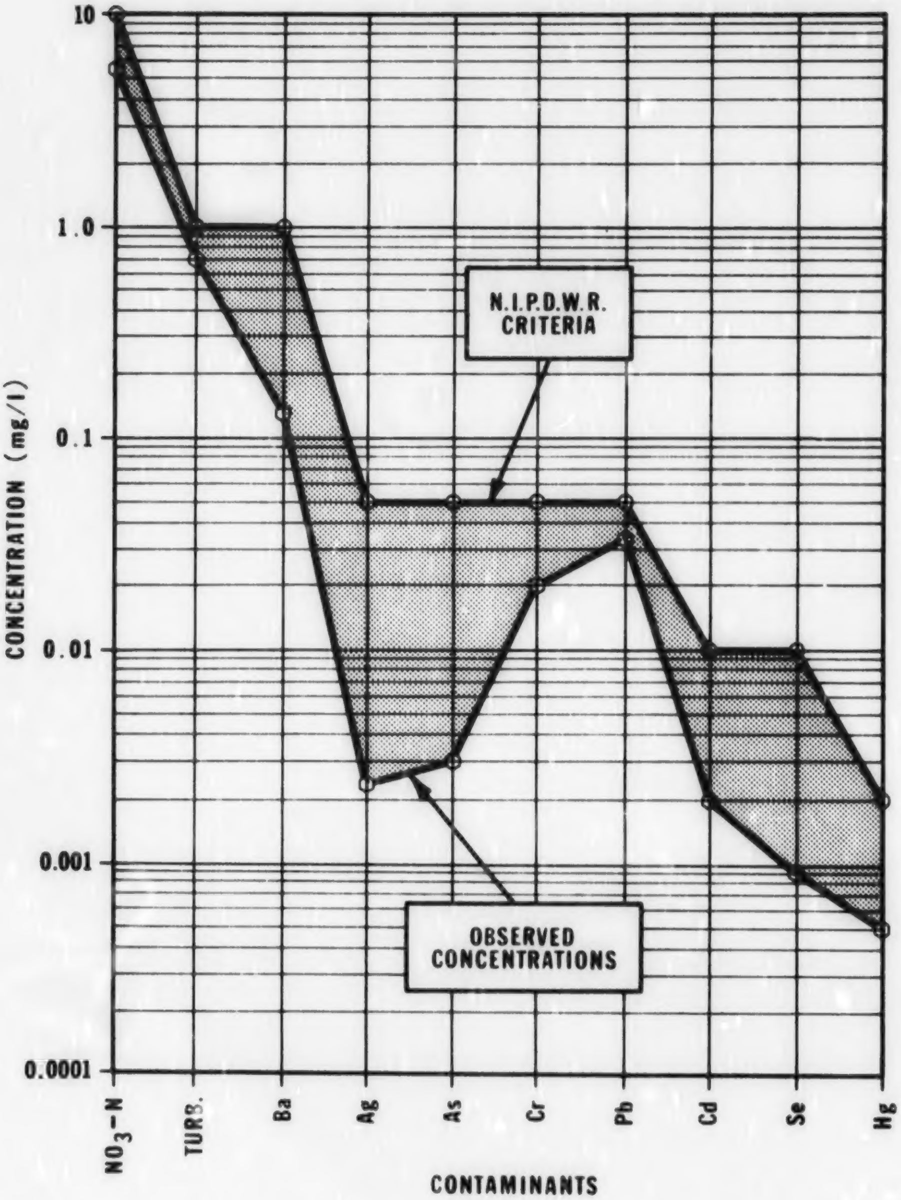

Figure 54. Comparison between the NIPDWR criteria and product water quality.

occur if this research was repeated. Additionally, the total Kjeldahl nitrogen concentrations observed in the influent to the activated sludge process (average = 24.1 mg/l) are lower than the 30 to 40 mg/l which might normally be anticipated in a municipal wastewater. For these reasons, nitrate nitrogen concentrations should still be considered a potential problem to the potable reuse of wastewaters.

Turbidity

Although some difficulties were experienced in the operation of the filter, the turbidity values observed for the product water meet the NIPDWR standards in all respects.

Metals

The means of the metals concentrations observed in the product water were considerably lower than the standards promulagated in the National Interim Primary Drinking Water Regulations (NIPDWR). The metals concentrations observed in the activated sludge effluent were also lower than the criteria defined in the NIPDWR. The mean concentrations of only three metals (cadmium, chromium, and lead) in the effluent from the primary clarifiers at the White Rock STP exceeded the EPA standards.

Three individual weekly composite samples exceeded the NIPDWR criteria for one individual metal. Chromium was found at 0.145 mg/l in the tenth week, lead was present at 0.059 mg/l during the twelfth week, and a mercury concentration of 5 micrograms per liter was found during the fifteenth week.

Biocides

Determinations for chlorinated hydrocarbons and chlorophenoxys were made on only one twenty-four hour composite sample collected from 12 noon October 24, 1974 to 12 noon October 25, 1974. The results are summarized in Table 22, and all compounds were present in concentrations much lower than the NIPDWR standards.

TABLE 22

RESULTS OF BIOCIDE DETERMINATIONS ON PRODUCT WATER

COMPOUND	EPA Standard (mg/l)	EPA Standard (ng/l)	Observed Concentration (ng/l)
Chlorinated Hydrocarbons:			
Endrin	0.0002	200	< 2
Lindane	0.004	4,000	< 0.3
Methoxychlor	0.1	100,000	<15
Toxaphene	0.005	5,000	N.A.
Chlorophenoxys:			
2,4-D	0.1	100,000	1,750
2,4,5-TP	0.01	10,000	<50

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